Summaries of the projects of the

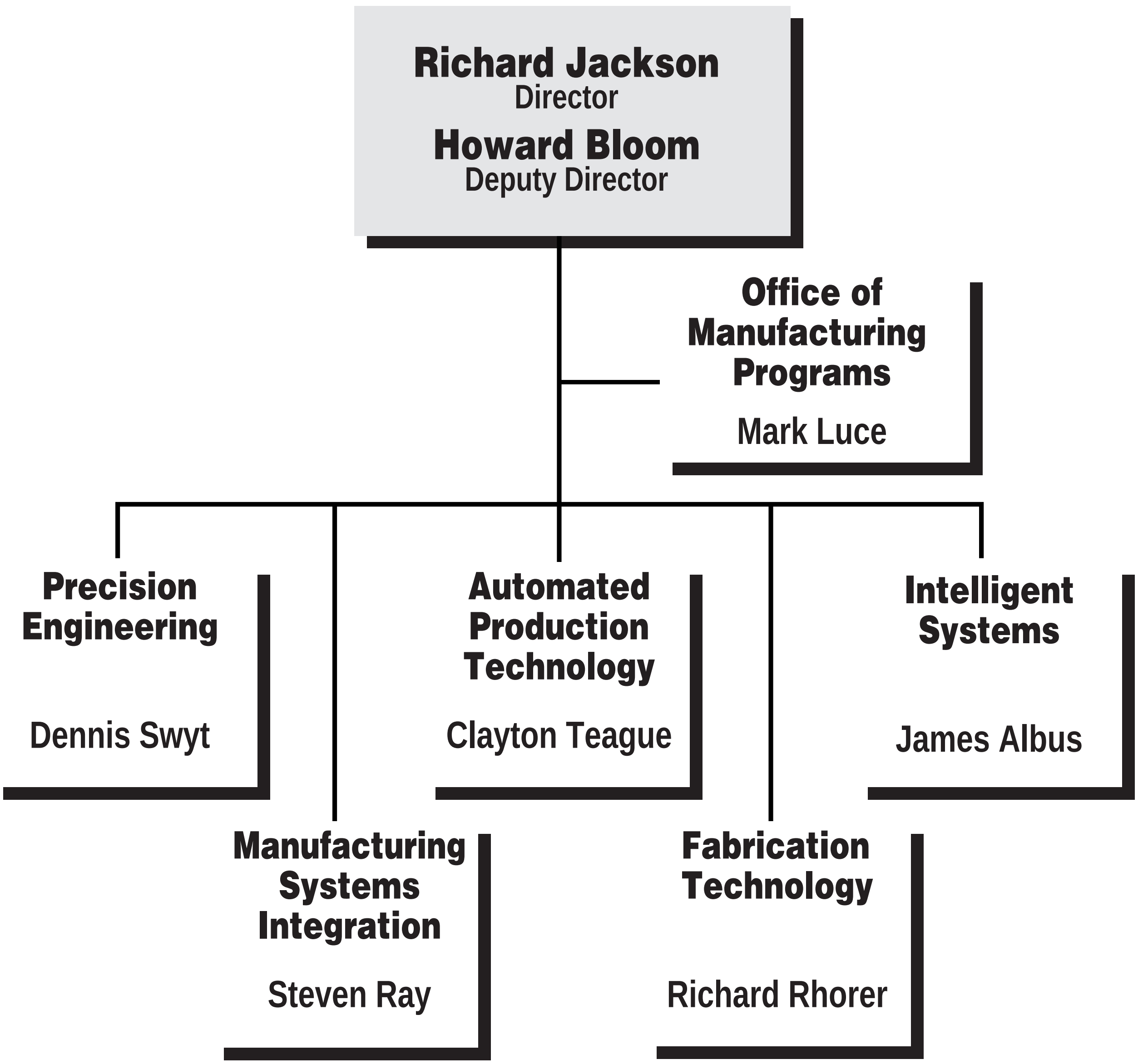
1998 Manufacturing Engineering Laboratory

Improving the competitiveness of U.S. Manufacturing by working with industry to develop and apply measurements, standards, and infrastructural technology

NISTIR 6122

NIST

U.S. Department of Commerce
Technology Administration
National institute of Standards and Technology


Richard Jackson
Director
Howard Bloom
Deputy Director
Office of Manufacturing Programs
Mark Luce
Precision Engineering
Dennis Swyt
Automated Production Technology
Clayton Teague
Intelligent Systems
James Albus
Manufacturing Systems Integration
Steven Ray
Fabrication Technology
Richard Rhorer

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Abstract

The National Institute of Standards and Technology's Manufacturing Engineering Laboratory (MEL) works with the U.S. manufacturing industry to develop and apply infrastructural technology, measurements, and standards to meet their needs. This report contains summarizes of MEL's projects that are in support of the U.S. industry's needs. Each project summarizes the resources, objectives, industry needs that are addressed, accomplishments, current year plans, five-year plans, and related measurement and standards work.

Keywords

Manufacturing, manufacturing engineering, technology, measurements, metrology, standards

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For More Information

Manufacturing Engineering
LaboratoryNational Institute of Standards and Technology
Building 220, Room B322
Gaithersburg, MD 20899-0001

Phone 301-975-3400

Internet address: www.mel.nist.gov

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Introduction

To remain competitive in today's global market, U.S. manufacturers must constantly improve quality, reduce manufacturing costs, and deliver products more quickly and at lower cost. Unfortunately, to do this requires ever-tightening geometric tolerances, more sophisticated part geometry, and advanced intelligent processes. The Manufacturing Engineering Laboratory (MEL), one of the National Institute of Standards and Technology's (NIST) seven measurement and standards laboratories, aids the manufacturing community by providing the measurement tests, tools, and calibrations that are essential for controlling manufacturing processes accurately with high precision and high quality.

MEL's work accelerates the rate at which manufacturers can insert advanced manufacturing technologies into their systems. It also improves on-line quality assurance processes that enable the manufacturing industries to adopt these advanced technologies more quickly. MEL supplies U.S. industry with the measurement methods and standards that support sensor and control technologies for closed-loop process control, as well as accurate inspection techniques that increase precision, quality, productivity, and cost efficiency. In addition, MEL provides a shared, distributed testbed (call the National Advanced Manufacturing Testbed or NAMT) where scientists and engineers from industry, academia, NIST, and other government agencies can work collaboratively to solve measurement and standards issues that impede companies and industries from taking full advantage of information technology to enhance their manufacturing capabilities.

U.S. industry depends on MEL's services to assure dimensional compatibility of items manufactured at different sites and satisfy requirements for tractability to national standards. MEL also participates with other research agencies to foster partnerships among academia, industry, and government that will keep the U.S. at the cutting edge of information and communication technologies for manufacturing.

All aspects of the manufacturing process from verifying part specifications (i.e., length, mass, force, acoustics, and ultrasonics) and characterizing machine performance to standards development and verification are influenced by MEL's work. The manufacturing industry served by this organization comprises approximately one third of the manufacturing sector's total contribution to the gross national product and includes the automotive, commercial aircraft, consumer electronics, and machine tool industries. This group of manufacturing industries accounts for almost one half of the U.S. trade deficit. MEL achieves its level of manufacturing influence by conducting research, providing measurement and calibration services, and working with the manufacturing industry in the development of national and international standards.

The work of MEL's Precision Engineering Division (PED) centers on the area of high-precision dimensional measurements for precision-engineering systems. MEL's Automated Production Technology Division (APTD) studies measurements and interface standards for automated production technology systems with emphasis on machine tools. MEL's Intelligent Systems Division (ISD) works with industry on standards and open-systems architectures for intelligent manufacturing systems. Interoperability standards, information models and frameworks for integrating manufacturing systems issues fall within the domain of MEL's Manufacturing Systems Integration Division (MSID). MEL's Fabrication Technology Division (FTD) provides part fabrication and a working "machine shop floor" collaboration for NIST and MEL researchers. MEL's Office of Manufacturing Programs (OMP) oversees the NAMT program. Even though each of the divisions has its own specialty, collaborations between groups is quite common.

MEL's programs support two of the major themes within the Department of Commerce's mission as stated in the

Commerce Strategic Plan: build for the future and promote U.S. competitiveness in the global marketplace by strengthening and safeguarding the Nation's economic infrastructure and keeping America competitive with cutting-edge science and technology and an unrivaled information base.

Within the past year, MEL's management team created its own strategic plan to help the organization with a similar mission of improving the competitiveness of U.S. manufacturing by working with industry to develop and apply infrastructural technology, measurements, and standards. The management team set five goals for the organization:

Goal 1: Laboratory research and development: Perform research planned and implemented in cooperation with industry that anticipates and addresses the most important measurement and standards needs in a timely fashion.

Goal 2: Physical-based National and International Systems of Standards and Measurements: Strengthen the national systems of standards, measurement, measurement traceability, and conformity assurance and provide leadership in harmonizing international measurements and standards to facilitate trade

Goal 3: Information-based National and International Systems of Standards and Measurements: Provide leadership in the development, testing and harmonization of information-based standards and specifications of strategic importance to U.S. manufacturing

Goal 4: Internal Management: Improve the management of the technical programs, measurement services, standards activities, and fabrication services -- which will include planning, prioritization, direction, and delivery of results

Goal 5: Customer satisfaction and program recognition: Continually seek feedback from customers in daily interactions and more formally in workshops designed to solicit customer needs; and foster broader recognition by stakeholders of the impact of the MEL's activities.

This annual report contains a "year-in-review" and summaries of the Manufacturing Engineering Laboratory's 1998 research projects and programs. The "year-in-review" contains examples which highlighted MEL's achievements during fiscal year (FY) 1997. Each project summary gives the reader a encapsulated view of: the research's primary objective, industry needs addressed by this research area, technical approach, prior year accomplishments, FY1998 plans, the project's five year goals, its work within the standards and measurement services area, and names the MEL strategic goals that are supported by this project.

MEL maintains a website at http://www.mel.nist.gov to provide more information about its organization, opportunities for Guest Research or collaboration, research facilities, or programs. Further information can also be obtained by contacting by mail:

Dr. Richard H.F. Jackson, Director of the Manufacturing Engineering Laboratory,
NIST, Building 220, Room B322,
Gaithersburg, MD 20899,
by phone: (301) 975-3400, or
by e-mail: Jackson@nist.gov.

Fiscal Year 1997: The Year in Review

Through its research results and services in metrology and infrastructure technology, the Manufacturing Engineering Laboratory (MEL) supports U.S. industry by strengthening its measurements and standards foundation. MEL's program stretches from basic metrology and national standards traceability to manufacturing information exchange methods and systems integration technologies. It encompasses machine and process characterization methods and intelligent machine and process control technologies.

Industry uses MEL's measurement-related research results and data to realize interface standards, manufacturing systems architecture and models, and manufacturing engineering tools. Based upon the impact of its work, MEL is a primary resource for industry in infrastructure technology, measurements, and standards.

In 1997, MEL continued to improve its measurements expertise and the services it provides, continued to upgrade its facilities, and migrated into new technologies in anticipation of more demanding needs by industry in the future. MEL has consistently had a successful record of meeting manufacturers' needs for measurement and science-based standards, research results, calibration services, measurement tools, test methods, and software conformance tests. The success derives from the collaboration with industry where MEL researchers learn first-hand about industry needs.

MEL's accomplishments in 1997 have contributed to U.S. industry's significant progress toward next-generation manufacturing. Individual firms and consortia collaborated with us to develop new technologies and standards, and showed particular interest in MEL's new collaborative testbed. We work with manufacturers, suppliers, vendors, and standards organizations in this new environment to accomplish Information Technology-Based Manufacturing.

It is not enough for MEL to perform its mission of research and development of measurements, standards and infrastructure technology as related to manufacturing. We must also ensure that this effort is done in collaboration with industry (and universities and other government agencies) and that our results are transferred as appropriate to our customers. We measure our performance through the impacts that are realized by our products, the recognition of our scientists and engineers, the type of interactions with our customers, and the quality of our accomplishments. The following are highlight examples of our performance in each of these categories. The reader should note that the following entries were submitted to the NIST Public and Business Affairs office during the Fiscal Year (FY) 1997 MEL monthly reports and no attempt was made to recognize one project over another.

Category: Accomplishments

The following accomplishments are grouped into the three primary MEL mission areas: Measurements, Standards, and Information Technology.

Measurements

Latest Automated Diameter Calibration System at NIST

A new calibration system has been developed for measuring cylinders, thread and gear measuring wires, and balls. The user-friendly system was designed, engineered, and tested by Jay Zimmerman, John Stoup, and Dennis Everett of MEL's Precision Engineering Division (PED). The software system, developed by Jay Zimmerman, allows NIST laboratory personnel to carry out a substantive measurement assurance program using an efficient and practical standalone personal computer (PC)-based workstation for all reference standard master cylinders, thread and gear measuring wires, and balls. With present measurement designs, typical 2-sigma uncertainty estimates of the calibrations by mechanical intercomparison have been substantially reduced from between 85 and 95 nanometers to between 50 and 75 nanometers for steel cylinders and thread and gear measuring wires and slightly larger for balls. These figures reflect nearly a 50 percent reduction over past years. Much of this reduction is a direct result of improved and frequent surveillance of a complete, yet nearly 90 percent smaller, NIST calibration history. On-line use of a new, state-of-the-art micrometer built by John Stoup also contributes to the reduced uncertainty estimates. The new system continues to use a special database and exclusive analysis software to record customers' measurement histories and, by that, reduce risks of reporting inaccurate measurements and improving overall measurement confidence.

M^3 Measures Gratings for NASA's AXAF Project

Using the Molecular measuring machine (M^3), two gratings have been measured for National (US) Aeronautics and Space Administration's (NASA) Advanced X-ray Astrophysical Facility (AXAF Project). The gratings have lines that are nominally at 200 nm and 400 nm pitches respectively. They are to be used as primary standards in the production of high-energy transmission gratings (HETG) by the Center for Space Research at the Massachusetts Institute of Technology. The HETGs are an important component of the X-ray spectrometer system on the AXAF-I space telescope. Launch of the AXAF-I satellite on the shuttle is scheduled for September 1998.

To measure the average pitch of these primary standard gratings, M^3 used a single line scan operating mode to count lines across a 10 mm span. This line count was divided into the total distance, given by M^3's high-resolution, Michelson interferometers, to yield highly precise measurements of the pitch. The analysis and cross checking of the pitch measurement data is still in progress, but the preliminary measurements are 200.011 nm +/- 0.008 nm (2 sigma) and 400.81 nm +/- 0.02 nm (2 sigma). These measurements represent a fractional uncertainty of only 40 ppm, far exceeding the capabilities of any commercially available scanning probe microscope. Further note that the feature size is not resolvable with most optical metrology systems and its long distance is outside the range of most electron microscope metrology systems.

Heat-Treated Steels with Rockwell-C-Hardnesses

Many precision components that must resist wear in harsh mechanical, thermal, and chemical environments are manufactured from heat-treated steels with Rockwell-C-hardnesses in the range of 50-65. Typically, to attain increased precision and good surface finishes, it is better to machine these components in the hardened state. In the past, the only reliable method for doing so has been grinding. Due to the high costs associated with grinding, other methods are sought. Recent development of new tougher tools has made it possible to turn and mill steels in their hardened state. However, attainable precision and surface finish is limited by large cutting forces that can cause static and dynamic distortion of machine, rapid tool wear, and unsteady material flaw. Understanding these effects is necessary if hard turning is to become an effective method for producing high-precision components.

Matt Davies and Steve Fick from t APTD, in cooperation with Chris Evans from the PED, recently examined the dynamics of material flow in finish hard turning. They demonstrated that for most practical machining conditions, material flow is dominated by the formation of segmented chips due to the formation of localized shear bands that form at frequencies in the range of 50 kHz to 120 kHz. To measure the corresponding temporal variations in the stresses acting on the tool during cutting, a polyvinylidine difluoride film was sandwiched between the tool insert and the tool holder to provide a high-frequency sensor. Frequencies measured with this sensor corresponded well with estimates of segmentation frequencies made from the study of the geometry of chip segments. The sensor developed for this purpose potentially may be used as a process monitoring device for the detection of undesirable events such as tool wear and built-up edge.

Finish Machining of Hardened Steels v.s. Grinding

Finish machining of hardened steels has been receiving increased attention as an alternative to grinding. Potentially, single-point cutting offers benefits over grinding such as lower equipment costs, shorter setup time, reduced process steps, better surface integrity, and elimination of metal-working fluid. However, tool wear remains a major cost-related barrier. Two MEL researchers, Kevin Chou from APTD and Chris Evans from the PED, have performed studies of finishing performance in turning of hardened powder metallurgy (PM) American Iron and Steel Institute (AISI) M50 steel using cubic boron nitride tools. Their data indicate that tool wear and flank wear rate are unusually small and relatively insensitive to cutting conditions. They attribute these findings to refined transition metal carbides in workpieces that tend to reduce chemical reactivity during cutting and minimize abrasive wear of cutting tools. Surface finish obtained at a fine feed and small depth of cut is in the range of 60 nm to 120 nm Ra. These results suggest that PM steels might be used for machinability enhancement in high-speed finishing, hardened die, and mold processes.

Support of NIST Standards: The Fabrication Technology Division

Support of NIST standards work is an important part of the mission for the FTD. Bob Clary, an FTD machinist, built a sophisticated ball plate designed by the large scale metrology group PED. This type of ball plate is being evaluated for use in the calibration of coordinate measuring machines. Making this ball plate involved the precision machining of 41 special seats for the mounting of precision spheres. The design allows the 15.875 mm diameter steel spheres to be probed from either side. With this design, it is necessary to machine away approximately 75 percent of the original aluminum blank and leave the posts with the spherical seats. To complete this job, Clary worked from the Computer-Aided Design (CAD) drawing of the ball plate. Clary spent about 16 hours programming his Computer Numerical Control (CNC) Hurco milling machine, about eight hours actually machining away the aluminum material, and then about two hours deburring and cleaning up after the job. Technicians from PED mounted the spheres and handled the calibration and use of the ball plate; however, as follow up to this job--as is typical with many of the jobs completed by FTD--feedback was sought on how well the ball plate functions. Listening to suggestions on what might be done differently in the future helps FTD continually improve its ability to manufacture these types of artifacts.

Standards

New ASME/ANSI Standard for Surface Texture Published

The American Society of Mechanical Engineers (ASME) recently published the American National Standard ASME B46.1-1995, entitled “Surface Texture (Surface Roughness, Waviness, and Lay).” This is a comprehensive revision and augmentation of the ASME standard B46.1-1985 on the same subject. Ted Vorburger of PED led the editorial committee that oversaw the revision. Vita Gagne, also of PED, provided editorial assistance and graphics support. In addition to a comprehensive discussion of definitions and procedures for the use of contacting stylus-type techniques to measure surface texture, the present revision contains several new sections that encompass advanced area profiling techniques, such as atomic force microscopy and phase shifting interferometry, which also provide valid and useful descriptions of surface topography at the nanometer and subnanometer levels of resolution. The standard, therefore, will be useful to engineers in a number of industries, including mechanical parts, semiconductors, and optics.

Remote Access and Control of Sensors and Actuators Via WWW Demonstrated

At a recent Sensors Expo held in Boston, two researchers in APTD, Richard Schneeman and Kang Lee, demonstrated how the Institute of Electrical and Electronic Engineers (IEEE) P1451.2 Draft Smart Transducer Interface Standard for Sensors and Actuators can be implemented to access data from remotely located sensors using World Wide Web Technology. In that demonstration, a temperature sensor and an actuator were connected to a control network located in the Sensor Integration Laboratory at NIST in Gaithersburg. From Boston, the site of the demonstration, the temperature sensor was scanned and the cooling fan at NIST remotely controlled using Internet and World Wide Web technology through modem and commercial telephone service. Live audio/video provided feedback for real-time confirmation of remote command execution.

This demonstration clearly illustrated not only the benefit to be derived from standardization of sensors and networks interfaces that allow “plug and play,” but also the power of Web technology for remote access and control of sensors and actuators.

Stainless Steel Standards

Zeina Jabbour of APTD completed the final report on work performed by NIST for the international comparison of stainless steel kilogram standards organized by the Working Group on Mass Standards of the Consultative Committee for Mass and Related Quantities of BIPM. The pilot laboratory is Bureau International des Poids et Mésures BIPM, which will be responsible for preparing a final report on the international intercomparison. Other participating countries are Canada, Japan, China, Australia, Italy, Netherlands, United Kingdom, Russia, Slovakia, Germany, and France.

The intercomparison provides traceability between the participating countries’ secondary stainless steel standards from which are derived the working standards used for the dissemination of the mass unit. It also benchmarks the countries’ research capabilities in disseminating the mass unit from the primary platinum iridium standards to the secondary stainless steel standards.

New STEP Class Library Software Available

Release 3.0 of the NIST STEP (Standard for the Exchange of Product data) Class Library which implements the C++ binding of the STEP Standard Data Access Interface (SDAI, i.e., ISO 10303-23) is now complete. This software release contains many updates supporting the latest version of the emerging standard, as well as, support for namespacing and multi-schema, enhanced handling of complex entities, and use of the STEP data with ObjectStore Object Oriented Database and Orbix (CORBA implementation).

Infrastructure Technology

NIST Delivers Ground-based Video Data to DARPA

The goal of theISD's Ground Video Data Collection project is to collect and distribute video and related information that supports computer vision research in applications such as surveillance and monitoring, tactical reconnaissance, and physical security. The project is funded by the Defense Advanced Research Projects Agency (DARPA). The availability of the first set of data has been announced to the DARPA research community. These data consist of a sequence of calibrated video images collected from a camera mounted on the NIST High Mobility Multipurpose Wheeled Vehicle (HMMWV) traveling off- and on-road at speeds of 8kph to 16 kph (5mph to 10mph). Most previous video data collections to support research have consisted simply of recorded video. Our data collection effort, on the other hand, involves the capture and synchronization of other data with the video. Currently, these data consist of the vehicle's forward velocity and turning rate, collected using an inertial navigation system on-board the vehicle. This inertial data is associated with each image frame, and can be used to recover the vehicle's position and orientation when each frame was taken. In addition camera calibration parameters have been obtained using a large building as a calibration target.

Software for reading the data files and interpreting the inertial data was also made available. The video, inertial data, and camera calibration data, plus supporting software and documentation are available on-line at http://isd.cme.nist.gov/staff/coombs/projects/ground-video/.

EMMA Successfully Demonstrates Simulated Nuclear Waste Retrieval

The EMMA (Easily Manipulated Mechanical Armature) project team has successfully demonstrated simulated nuclear waste retrieval using a prototype 10m long, serpentine robotic arm recently developed by Grey Pilgrim LLP, in collaboration with engineers from ISD as Cooperative Research and Design Agreement (CRADA) partners. The demonstration highlighted EMMA's long-reach manipulator effectively deploying a scarifying end-effector (i.e., a 30,000 psi water jet cutter with waste retrieval suction) to retrieve hard-packed, concrete-like waste simulant and softer, more sludge-like waste simulant. The waste simulant trays were placed approximately 6m below and at a 6m radius from EMMA's base. During all waste retrieval passes, the EMMA manipulator performed in a very stable fashion while demonstrating its inherent dexterity and redundancy.

Development of this EMMA manipulator was sponsored by the Department of Energy's (DoE) Hanford Tank Initiative (HTI) to demonstrate innovative new technologies applied toward cleanup of underground nuclear waste storage tanks. The overall remediation plan is to deploy a 20 m EMMA manipulator from a mobile NIST RoboCrane structure over the underground tanks to allow insertion and controlled maneuverability of similar scarifying end-effectors throughout the tank volume. The combination of RoboCrane and EMMA technologies is well suited to perform this task because of several shared features: they both have very favorable strength to weight ratios, they both are easily scaled for different tank sizes and they both provide exceptional stiffness and control of payloads at very low cost.

The DoE HTI sponsors were excited about this recent demonstration. They recognize that the EMMA long-reach manipulator shows great promise for several reasons:

- It is completely cable driven so all expensive actuators and controls remain outside the tank and are available for reuse.
- It is extremely lightweight compared to other long reach manipulators.

- Its modular bending and static segments can be easily reconfigured to custom design the manipulator for a given set of constraints.
- It can be scaled up in length relatively easily.

In its current configuration, EMMA has a maximum diameter of 60 cm near the base and reduces down to 45 cm at its tip, 10 m away. Its overall weight is approximately 442 kg, and it can easily wield a 45 kg end-effector. A single PC computer and four joysticks provide control over EMMA's four bending stages with one joystick controlling two degrees of freedom per stage. Each stage has four steering cables that act in pairs by applying opposing bending forces. Differential tensions in each pair of cables cause bending in the stage. Two additional degrees of freedom are available to the operator. One allows an overall up/down motion of the entire EMMA arm by lifting EMMA's base frame vertically (simulating RoboCrane's motion). The other allows for pitching of the end-effector to maintain an orientation normal to the target surface.

In addition to waste retrieval applications, this technology has other potential applications. For example, Boeing's Commercial Airplane Group and Defense Group, after seeing a demonstration of EMMA's dexterity and RoboCrane's stability, expressed an interest in applying these technologies toward their large-scale manufacturing and refurbishment processes. The EMMA team will be visiting Boeing's new 777 manufacturing facilities soon to further investigate potential collaboration.

Machine Tool Performance Data Dictionary Developed

Efficient access to relevant data on machine tools is an essential enabler of virtual machining. Hans Soons, a researcher in APTD, prepared the first version of a data dictionary that contains the names and definitions of data items necessary to describe the conditions, setup, and measurement results of performance evaluation tests on machine tools. The dictionary is a repository of information describing the data to be contained in a database on machine tools. It is, therefore, metadata or "data about the data." Specifically, the data dictionary includes the names and definition of the data items in the repository, the types and sizes of these data items, and the constraints on each data item. The dictionary was developed as a database using a readily available commercial package. A user friendly interface was developed to facilitate use of the dictionary and to allow for future growth. In its present version the dictionary contains over 250 definitions. The dictionary is being developed as part of APTD's National Advanced Manufacturing Testbed (NAMT) project on machine tool performance models and machine tool data repository. It will be tested by researchers participating in the NAMT project both at NIST and at various industrial sites. The overall goal of this project is to provide manufacturing designers and engineers with the virtual tools required to predict machine tool performance and parts accuracy with minimal prototyping.

GM STEP Translation Center Receives CALS Implementor Honor Roll Award

General Motors (GM) received the Continuous Acquisition and Life cycle Support (CALS) Implementor Honor Roll Award from the U.S. CALS Industry Steering Group for using the new international standard STEP (Standard for the Exchange of Product model data, officially ISO 10303) to transfer product designs between teams using different computer-aided design (CAD) systems. STEP replaces less effective methods of data exchange that have been barriers to streamlining the process of developing new products. As a result of STEP, General Motors and its suppliers are realizing reductions in costs and time to market, while enhancing the quality of their products and agility of their processes. The General Motors STEP Translation Center is the means for exchanging designs for new products among GM divisions, their customers, and their suppliers. The center is increasing the degree of cooperation on the design of new products, which will move the products into production in less time and at a reduced cost. Partners in this venture are Delphi Automotive Systems, GM Powertrain Division, Delco Electronics Corp., GM Small Car Group, Saturn Corp., EDS/Unigraphics, and Dassault Systems.

Bob Booth, director of Global Infrastructure in GM's Information Systems and Services Group and chairman of the PDES, Inc. Executive Board, stated, "The STEP Translation Center is important as a building block for improved processes to manage and share technical and business data necessary for realization of synchronous manufacturing within GM."

NIST is the Secretariat of International Organization for Standardization on Subcommittee on Industrial Data (ISO TC184/SC4) under which STEP was developed and has been a heavy technical contributor to this international standard. Further, software tools developed under the Systems for Integrated Manufacturing Applications (SIMA) STEP Conformance Testing project have been used extensively by industry. These tools isolate and enable rapid resolution of implementation issues found in the commercial CAD translators that are used by this center and others who are adopting STEP.

Category: Recognition

We included three recognition types: (1) personal recognition for exceptional services, (2) appointments to boards and journals, and (3) special project or product recognition.

Personal Recognition

MEL/MSID Employee Elected to AAAS Fellow

Russell A. Kirsch, an employee in MSID recently earned the honor of being elected as an American Association for the Advancement of Science (AAAS) fellow. Each year the AAAS Council elects members whose "efforts on behalf of the advancement of science or its applications are scientifically or socially distinguished." Mr. Kirsch is being honored for "development of computer image processing and its application to science, technology, the arts, and the problems of government." The honor of being elected a Fellow of AAAS began in 1874 and is acknowledged with a certificate and a rosette. Mr. Kirsch will receive his certificate and rosette in Philadelphia, PA on Saturday, February 14, 1998, during the AAAS Fellows Forum, which is part of the Association's Annual Meeting.

MEL Staff Member Receives Awards for Communication of Research

Don Libes, a computer scientist in MSID, received the Best Paper Award at the 1997 Tcl/Tk Conference. The paper, entitled "Writing a Tcl Extension in Only ... 7 Years", was a retrospective on the pragmatics of software development and delivery in continually changing environments. Thirty-eight papers competed for the award.

At last year's Tcl/Tk Conference, another presentation by Mr. Libes earned the Best Presentation Award. That presentation, entitled "Writing CGI Scripts in Tcl", was a description of elegant techniques for automation and management of dynamic documents with specific application to WWW forms and pages. The 1996 award was actually presented to Mr. Libes at this year's meeting.

PED Employee Receives Special Award from ASME

The American Society of Mechanical Engineers (ASME) recently awarded Vita Gagne, an Editorial Assistant in the Surface and Microform Metrology Group in PED, a special commendation for her editorial assistance and graphics support of the recently published ASME Standard B46.1-1995, "Surface Texture." ASME B46.1-1995 is a comprehensive revision of the standard with an extensive discussion of procedures for surface profiling instruments and a new set of definitions of terms for the emerging fields of area profiling and area averaging techniques. The ASME specifically commended Ms. Gagne for her "creative and diligent contributions to the development of the B46 Surface Texture Standard, and as a result, for advancing the level of Engineering Standards in the United States."

Appointment Recognition

McLean Joins Editorial Board of "Computers in Industry"

Chuck McLean, a computer scientist from MSID, was asked to join the Editorial Board of the Elsevier's Journal of Computers in Industry by Hans Wortmann, editor-in-chief. He will be assembling a special issue on simulation on virtual manufacturing during the coming year. McLean is also on the Editorial Board of the Taylor & Francis Journal of Production Planning and Control.

Jackson Appointed to IMS ICE Committee

Richard H.F. Jackson, MEL director, was named one of the U.S. members of the Intelligent Manufacturing Systems' (IMS) Committee of Experts (ICE). The IMS Program provides a framework for international collaborative research and development in advanced manufacturing. ICE is responsible for encouraging relevant IMS projects, enhancing the program overall, monitoring the list of technical themes, and identifying areas of overlap and possible collaboration among projects. Each region participating in IMS -- Australia, Canada, Japan, Switzerland, European Union, and the United States -- has appointed two members to ICE. Margaret Eastwood, Motorola vice president and corporate director, is the second U.S. ICE delegate. Jackson will serve on ICE's Technical Theme Working Group while Eastwood will serve on a team that will integrate key elements into an international marketing plan.

Project/Product Recognition

RRM Intramural Results Highlighted

A recently issued news release, prepared by the NIST Public and Business Affairs Division, describes activities and results of the NIST Rapid Response Manufacturing (RRM) Intramural Project. This release has resulted in follow-on articles planned by external organizations, including NACFAM Weekly, Technical Insights/Advanced Manufacturing Technology, and Machine Shop Guide. Other requests for further information were received from Giddings & Lewis and the Association for Manufacturing Technology. In addition, the Institute of Advanced Manufacturing Sciences expects to include NIST RRM project activities and related manufacturing resource data standardization efforts in upcoming issues of two industry newsletters, Machining Briefs and MetCAPP News.

NIST Researcher Shares 1997 R&D 100 Award

Hans Soons, a researcher in APTD, shared a 1997 R & D 100 Award with Massachusetts Institute of Technology (MIT), and The Landis Division of Western Atlas, Inc., for co-developing a powerful tool, Machining Variation Analysis, for analyzing the accuracy of parts produced by machine tools.

This tool allows manufacturing engineers to simulate and predict the true shape of a manufactured part, including the effects of random and systematic variations. The user provides information on the nominal geometry of the part, the construction of the machine, the shape of the cutting tool, and the sources of error in the operation of the machine. With the parameters specified by the user, the Machining Variation Analysis determines the exact shape of the part, including consequences of the specified errors in machine operation. Using that shape, expected values of tolerances held on the part, as defined in geometric dimensioning and tolerancing, can be computed. The Machining Variation Analysis further allows the designer to assign statistical characteristics such as mean, standard deviation and distribution shape to random errors. This in turn allows calculation of yield rates, quality loss, and process capability. Thus, the Machining Variation Analysis improves design and manufacturing practices by providing instant feedback on the effects of design decisions.

Libes Interviewed

On February 13, 1997 Alfred Werner, Internetwork Broadcasting, interviewed Don Libes (a computer scientist in MSID) for 30 minutes on the Internet-Radio show "on Queue". The interview covered Libes' work involving Expect, (an interaction automation toolkit), STEP (ISO-10303, Standard for the Exchange of Product Model data) as well as his thoughts on the future. An audio link is available at http://www.clubnetct.com/media/media.htm (see the link "on Queue").

Category: Impacts

This category highlights how products and services that MEL provides to industry have made a difference in their ability to be competitive.

Blind Tip Reconstruction Incorporated in Commercial SPM

Digital Instruments (DI) has incorporated a version of blind tip estimation into their Dimension 7000 instrument. This technology was developed at NIST and published in a 1994 paper ("Morphological estimation of tip geometry for scanned probe microscopy," J.S. Villarrubia, Surf. Sci. 321, p. 287, 1994). Blind tip estimation provides a means of estimating tip geometry for scanned probe microscopes by imaging tip characterizer artifacts. Unique to this technique (and the reason for the word "blind" in its name), the geometry of the tip characterizer need not be known independently. DI's implementation is used to qualify tips. The tip shape is compared to nominal values and classified as good, worn, or bad, so the instrument user can determine whether the tip needs replacing. (The Dimension 7000 instrument features automatic loading of 200 mm semiconductor wafers, and appears to be targeted at dimensional metrology applications in the semiconductor industry.)

Multiple Precision Software Improves Algorithm Testing and Evaluation Program Service

The Algorithm and Testing And Evaluation Program (ATEP) is a special testing service offered by MSID to evaluate the performance of algorithms used in coordinate metrology software. Manufacturers can use ATEP to quantify their software uncertainty into uncertainty budgets as required by ISO 9000. The Algorithm Testing System (ATS) is the computational tool NIST uses in performing the ATEP service, which compares a customer's results to its own, highly accurate, reference algorithms. There exist a few key places in the ATS where it is advantageous that it perform arithmetic at greater than double precision. The multi-precision arithmetic would allow NIST to provide customers with the more accurate reference algorithms with lower uncertainties. However, pre-written multi-precision packages did not suit ATS' needs, so the Applied Systems Group staff, within MSID, wrote a multi-precision package in C++ to perform these arithmetic operations. With this new software, no special characters or routines need to be called when multi-precision operations are needed since the operators (+, -, *, /, >, <, =, etc.) have been overloaded. By overloading the function, a user uses the standard symbol to carry out the multi-precision operation (e.g., C = A * B works when A and B are any combination of single, double, or multi-precision numbers). Square roots and a few trigonometric functions were also written. Although the functions are expectedly slow, they work quite well. As a performance check, these routines were used to successfully calculate a few hundred digits of pi.

NIST Work Lauded in a Book

Don Libes, a Computer Scientist from MSID developed a software package called Expect (Version 5 released March, 1994). Expect is a tool for automating interactive UNIX applications such as telnet, ftp, passwd, fsck, rlogin, tip, etc. It is also useful for testing these same applications. Expect makes these applications simple to use and can make easy all sorts of tasks that are prohibitively difficult with anything else. Expect has been described in many books, articles, papers, and in fact, there is an entire book on it. Many companies are using Expect to automate tasks which ultimately has saved them money. Recently, a newly published book “Tcl/Tk Tools” [ISBN 1-56592-218-2], which describes the most significant 12 extensions for the Tcl community, notes in the forward that Expect was the first significant Tcl extension and was responsible for the initial crucial interest in the Tcl language.

Category: Interactions

Our interactions with industry, academia, and other government agencies include: Collaborations, Workshops/Conferences Held, Special Visits, and Presentations.

Collaborations with other Organizations

Ultrasonics and Your Future Dental Crown

The Ultrasonics group of APTD is assisting the Materials Science and Engineering Laboratory's Ceramics Division with sound velocity measurements of composite materials being evaluated for dental crown applications. Knowing the material density, the elastic moduli of the dental crown materials may be determined from the velocity data. It is important to calculate the elastic moduli of the material in order to determine if a specific material is suitable for a dental crown. Ideal dental crown material would give slightly under pressure but not enough to be springy. If the material does not give at all, then it is likely to break when you bite down. Two materials that are under consideration are glass-infiltrated alumina and spinel structures. The Ultrasonics group assisted with the ultrasonic measurements of the Young's modulus and Poisson's ratio that are used to assist with finite element and analytical modeling of the Hertzian contact damage response of these structures. (Like, when you bite down on that Tootsie Roll Pop, will you be swallowing a piece of the crown along with the tootsie roll?)

FTD More than a “Job-Shop”

The Fabrication Technology Division (FTD) provides part fabrication for many different divisions at NIST. In this way, FTD is often working as a “job-shop”--we accept a drawing, then we make and ship a part. However, FTD is more than a job-shop. Because we are part of NIST, we also do many special projects that help researchers. For example, recently FTD's Charles Brooks, worked directly with Ralph Siegel, of the Electricity Division on a small project. Ralph needed to make a set of Helmholtz coils. Charles set up a large lathe in the Main Shop at FTD as a winding machine. Ralph then wound and potted the coils to accomplish his special needs with Charles assisting. This type of teamwork is possible with our shop. In this case, we certainly do not have the expertise to design and wind coils so we couldn't simply provide the coils, but we do have some equipment and skills that can assist the scientist with a special requirement.

PED and MSID Join Forces to Assist U.S. Navy

As part of a U.S. Navy upgrade of submarine based vertical launch systems, contractors were beginning measurements of missile tubes. They suddenly realized that no one had performed an uncertainty analysis of the process. The Measurement Science Group of the Naval Warfare Assessment Division, Corona, CA contacted the PED Large Scale Coordinate Metrology Group and asked for immediate assistance to develop an uncertainty budget for these measurements. These launch systems present an interesting metrology problem for two reasons: one, the tubes are only 0.61 m (2 feet) in diameter by 7.3 m (24 feet) deep; and two, failure to conform to a small uncertainty in the bore size could mean dry-docking the submarines to re-bore the tubes, a very costly process. Steve Phillips and Chuck Fronczek, of PED, went to Newport, Rhode Island to monitor the measurement process. The following week, Steve Phillips, Bruce Borchardt (PED), and Craig Shakarji, of MSID, wrote a report using the measurement data that the Navy furnished. Craig Shakarji wrote a software package employing three fitting methods, which uses a Monte Carlo technique to determine uncertainty estimates under various conditions. As a result of this exercise, the Navy has adopted this new procedure to determine uncertainty.

MEL Staff Member Collaborates with Industry and Academia to Study Dynamic Effects in High Speed Milling

Matt Davies, a researcher in APTD is working with McDonnell Douglas Corporation, The Pennsylvania State University, The University of Florida and The University of Maryland to address the problem of dynamic errors in high speed milling. The speed and power of production-grade machining centers has been increasing rapidly over the past ten years. However, with these increased speeds, machining operations are becoming more complex. The combination of thin-walled components, longer, more flexible tools, and increased tool rotation rates significantly reduces the dynamic stability of the machining process. The Makino High Speed Mill, jointly owned by APTD and FTD, is being used in the investigation of the effects of dynamic errors on high speed milling.

MEL Supports Next Generation Internet Planning

NIST's Manufacturing Engineering Laboratory supported development of a multi-agency plan for implementation of the Next Generation Internet (NGI). MEL's responsibilities for the plan included development of descriptions for manufacturing applications that require the use of the NGI as well as descriptions for enabling technologies such as remote operations and collaboration.

NIIIP-AMMPLE Kickoff

On Nov. 21, 1996, Mary Beth Algeo and Mary Mitchell of MSID attended the kickoff meeting of the National Industrial Information Infrastructure Protocols--Agile Missile Manufacturing Pilot-Linking Enterprises (NIIIP-AMMPLE) project. This nine-month effort, scheduled to begin in January 1997, will serve to validate NIIIP technologies by establishing baseline “virtual enterprises” with the prime contractors of DARPA’s Affordable Multi-Missile Manufacturing (AM3) program and their supply chains. Prime contractors from AM3 include Lockheed Martin Electronics and Missiles, Lockheed Martin Vought Systems, Raytheon, and Texas Instruments. Participating members of the NIIIP Consortium include IBM, International Technegroup, Inc., Enterprise Integration Technologies, STEPTools, Inc., and UES Inc. NIST will serve a contracting agent and a technical reference with a focus on standardization.

Special Visits

Enhanced Machine Controller

On November 26, 1996, Fred Proctor, Will Shackleford, Mark Bello, Kathy Simon (the NIST photographer), and Rick Quintero visited a machine shop in Randallstown, MD, for a demonstration of automatic machining using a Bridgeport three-axis knee mill retrofitted with the NIST enhanced machine controller (EMC). The EMC software used was ported from the original General Motors EMC implementation to a single personal compuer (PC) computer running Windows NT. For the demonstration, a design was automatically cut into an aluminum part created using COREL DRAW software. The design was transferred into a PC-based CAD package from COREL DRAW in DXF format and then a RS274 code was generated as output using a post processor. The RS274 code then was used as input to the PC-based EMC controller to cut the part automatically.

Research Visit to Electrotechnical Laboratory, Tsukuba Japan

From May 27 - June 15, John A. Dagata of PED continued work on a collaborative research project at the Electrotechnical Laboratory (ETL) in Tsukuba, Japan. His hosts were Drs. H. Yokoyama, T. Inoue, and J. Itoh. This project was initiated during a previous research visit to ETL from December 1, 1996, to January 15, 1997, as an AIST Visiting Research Scientist. [AIST refers to the Agency for Industrial Science and Technology, Ministry of International Trade and Industry. It is the organization of the Japanese government that is responsible for operating the system of national physical and engineering laboratories.]

The research is related to scanned probe microscopy (SPM) applications, specifically, scanning Maxwell-stress microscopy (SMM). A method first developed at ETL, SMM is currently viewed as the most promising candidate for integrating SPM-based fabrication methods with an appropriate in-situ electrical characterization method. These visits have allowed Dr. Dagata to efficiently evaluate the implementation of SMM here at NIST in terms of sensitivity and spatial resolution for nanoelectronics fabrication. The resulting experience is of direct relevance to the joint MEL-Electronics and Electrical Engineering Laboratory (EEEL) Nanoelectronics Competence Project.

Dr. Dagata investigated a set of conducting phase-separated polymer samples that were prepared at NIST in collaboration with A. Karim and J. F. Douglas from the Polymers Division of the Materials Science Engineering Laboratory. The idea for the project originated at NIST as a means of providing a complex, challenging materials system for evaluating specific performance and compatibility aspects of SMM.

This multidisciplinary investigation has demonstrated a novel method for visualizing how individual polymer components of each phase in the system are distributed in the quasi-2D thin-film limit. As the film thickness is reduced below about 100 nm, interfacial interactions begin to play an increasingly important role in determining the equilibrium structure of the film. Experiments on 10 nm and 100-nm thick films of pure polystyrene (ps), pure conducting polymer (poly-3-octyl thiophene, b4), and (1:9) and (2:1) blends of ps:b4, both as-prepared by spin casting onto H-terminated silicon and after various annealing times and temperatures, establish the basis for the SMM contrast mechanism which permits discrimination between ps and b4 by their different dielectric signatures in the simultaneous SMM capacitance and surface potential imaging modes. This technique can then be used to look at sub-surface mixing on the sub-micrometer scale within the 100 nm thick films as they are annealed for increasing periods of time. When combined with optical microscopy, atomic force topography, and 3D imaging secondary ion mass spectrometry (SIMS), performed at NIST in collaboration with J. Fu, PED, and J. G. Gillen, Chemical Sciences and Technology Laboratory, this unique information provides a significantly enhanced understanding of the complex physical and chemical interactions driving quasi-2D phase separation.

Workshops/Conferences Held

NAMT Hexapod External Workshop

An external review workshop of the National Advanced Manufacturing Testbed (NAMT) Hexapod project was conducted at NIST on September 27, 1996. Eleven reviewers from industry, universities, and other government agencies participated in the workshop. The purpose of the workshop was to provide industry, academia, and other government agencies the opportunity to critique the overall focus, goals, and objectives of the Hexapod project. This includes the technical soundness of the project design as it relates to industry needs and the state of knowledge and practice in the field of Hexapod machining. Workshop participants provided written responses to questionnaires and participated in group discussions. The overall response was quite favorable, and many useful comments and suggestions were obtained. The questionnaire responses have been compiled and will soon be incorporated into a workshop summary report.

Intelligent Systems: A Semiotic Perspective

On October 20-23, 1996, ISD hosted the Intelligent Systems: A Semiotic Perspective conference at NIST, Gaithersburg, MD. The purpose of this conference was to stimulate a multi-disciplinary approach to the theory and application of intelligent systems so that an adequate engineering methodology can be generated. Sponsors of the conference included NIST, the National Science Foundation, the Institute of Electrical and Electronics Engineers, the Defense Advanced Research Projects Agency, and the U.S. Army Research Lab. The general chair of the conference was Jim Albus, the program chair was Alex Meystel, and the local arrangement chair was Rick Quintero. More than 150 participants attended the meeting. The pre-conference tutorial, “Applied Semiotics,” was attended by 45 participants. Two conference workshops were dedicated to intelligent manufacturing. One classified workshop centered on issues of defense applications. A coordinating group was formed with 24 active members. This group made a commitment to accomplish a number of ongoing tasks: to create a network, to create a World Wide Web site, and to disseminate methodological documents. The electronic mail based network has been established and is already functioning.

Intelligent Systems and Semiotics (IAS’97) Conference

The Manufacturing Engineering Laboratory's ISD hosted the third in a series of annual conferences on intelligent systems at NIST in Gaithersburg, Maryland, on September 22-25, 1997. The conference was co-sponsored by the Institute of Electrical and Electronic Engineers (IEEE) Control Systems Society, the National Science Foundation, and the Army Research Office. The theme of this year's conference was “A Learning Perspective” with papers presented by a broad cross-section of international researchers representing fields as diverse as bio-medical research and cognitive reasoning to evolutionary programming. The conference was preceded by a day of tutorials on Semiotics (the science of signs and symbols), the NIST Real-time Control System (RCS) Intelligent Reference Architecture, and Hierarchical Modeling and Understanding via Algebraic Automata Theory. The conference had an attendance of 105 people with 36 people attending the tutorials. The next conference in this series will again be hosted at NIST in Gaithersburg. It is being planned as a joint conference on the science and technology of intelligent systems. It will incorporate the IEEE International Symposium on Intelligent Control, IEEE International Symposium on Computational Intelligence in Robotics and Automation, and Intelligent Systems and Semiotics (ISIC/CIRA/ISAS'98) and will be held at NIST on September 14-17, 1998.

Workshop on Development of a STEP Application Protocol for Inspection

MEL’s National Advanced Manufacturing Testbed Framework Project sponsored a workshop to assess industry interest in development of standards for manufacturing inspection data. Representatives of 12 national and international corporations attended the September 4 workshop. The attendees, all manufacturing inspection domain experts, developed a list of the most significant problems in the areas of inspection planning and inspection data exchange faced by their organizations. The attendees postulated that standard, models in inspection information are very important to the successful implementation of advanced inspection systems. The process for developing standard models of information was adopted from the ISO Standard for the Exchange of Product Model data (STEP). The development of STEP information models, or Application Protocols begins with a scoping activity. The attendees developed an initial draft scope and activity model. This initial work will be soliciting comments from other industry experts. A follow-on workshop to continue collaborative development of standard manufacturing inspection information models will be held in early 1997.

Design Repository Workshop

The Design Repository Workshop held November 19-20, 1996, at NIST aimed at understanding the requirements for large-scale design repositories. The workshop, co-sponsored by Systems Integrations for Manufacturing Applications (SIMA) and DARPA RaDEO programs, was attended by nearly 40 participants (approximately half of the participants were from industry). Ric Jackson, director of MEL opened the workshop and provided an overview of the various MEL programs. Several industry case studies on current practices in design retrieval were presented and various needs for a large-scale design repository were identified. Current research activities in industry and academia were discussed. Representatives from DARPA, US-CERL, NASA, DOE, and NIST discussed various programs and initiatives related to the workshop topic. Roadmaps for research in particular STEP-based standards were produced during the breakout sessions. Workshop notes are being prepared and will be distributed to all participants.

STEP-Based Solid Interchange Format Workshop

A workshop, co-sponsored by SIMA and DARPA RaDEO programs, for STEP-based Solid Interchange Format (SIF) was held November 25, 1996 at NIST. Twenty-nine participants attended the workshop. Attendees included rapid prototyping tool vendors, users of these tools, academic researchers from electrical and mechanical engineering domains, and representatives from various government agencies (NIST, National Science Foundation, and Canadian NRC). The attendees felt a strong need for a STEP-based solid interchange format for solid free-form fabrication data exchange, due to the limitation of the current de facto data exchange standard -- STL. Discussions focused on limitations of current STL standard (lessons learned from developing a data exchange format) (CIF) for Very Large Scale Integration (VLSI) design/manufacture integration, features, and representation for the emerging SIF standard. A workshop proceeding is under preparation. A virtual conference using the Internet to gather further input from the attendees and other parties interested in the workshop topic also is planned.

NIST Hosts Workshop and Meetings on Product Data Exchange

On January 27, 1997, an industry workshop on using STEP for effective product data exchange was held at NIST Gaithersburg. The objective was to provide a business-based overview of the capabilities of STEP and progress on its successful use by industry. There were approximately 125 participants.

The workshop preceded the technical meetings of IGES/PDES (the Initial Graphics Exchange Specification/Product Data Exchange using STEP) Organization, a U.S. standards development organization. Included was a workshop between representatives of U.S. STEP proponents and of the Object Management Group

Manufacturing Domain Task Force on achieving compatible product data management specifications. Participants viewed it as a historic meeting between these two communities.

Other highlights of the week included U.S. position setting sessions on upcoming international ballots within ISO TC184/SC4; an implementers forum; discussions on an engineering analysis pilot activity; progress and issues on casting (AP223); forging (AP229), design to manufacture for composites (AP232), and technical data packages (AP232); relationship of CALS standards; demonstrations from the NIST National Advanced Manufacturing Testbed and Systems Integration for Manufacturing Applications programs; and a U.S. Technical Advisory Group Meeting.

IPO/OMG Workshop

A joint workshop was hosted of the IGES/PDES Organization (International PDES Organization - IPO) and the Object Management Group (OMG), which focused on achieving compatible specifications for product data management (PDM) systems. The workshop brought together members of the OMG Manufacturing Domain Task Force and the U.S.-based STEP "configuration control" and "documentation package" experts, industrial users, and software developers to work toward compatible standards for interfaces to PDM systems. Presenters from ISO and OMG gave brief description of their standardization processes, users presented their work and experience, and standards experts gave presentations on the scope and state of the respective PDM-related standards efforts. It became apparent that all these efforts are currently in a developmental state and even the recently adopted ISO 10303-203 standard is likely to be revised. Consequently, the latter part of the meeting was devoted to strategies for coordinating the nearly simultaneous international standards activities, and the foundation was laid for regular intercommunication and some joint work.

NIST and Next Generation Inspection System: Industry Partners Develop and Test Application Program Interfaces

The Next Generation Inspection Systems (NGIS) Application Program Interface (API) working group held a meeting at NIST on February 5, 1997. The goal of the working group is to develop API's for the use of inspection probes on coordinate measuring machines (CMMs) and machine tools. The probes considered are an Automated Precision Inc. 3-D analog touch probe, an Extrude Hone capacitance probe, and a SAMI laser triangulation probe. The API's provide an interface between the probes and the machine control system. The companies represented at the meeting include Advanced Technology and Research, Automated Precision, and Extrude Hone. Hughes, Wizdom, and SAMI have attended previous meetings. John Michaloski chaired the meeting; Sandor Szabo, Bill Rippey, and Marty Herman also participated (all from ISD). Implementations based on the initial API definitions already have begun. API libraries for the Automated Precision 3-D touch probe have been implemented.

These libraries and APIs then will be integrated into the NIST NGIS controller for testing and validation. Discussion at the meeting centered on the activities to be performed by NIST to test and validate. These libraries and APIs also will be integrated by Advanced Technology and Research into the K&T 800 machine tool controller at General Motors Powertrain and tested there. In addition, Automated Precision Inc. plans to integrate these libraries and APIs onto a Brown & Sharpe CM at Ford.

Industrial Workshop on Virtual and Distributed Machine Tool Performance Models and Data Repository

APTD held its 2nd Industrial Workshop on Virtual and Distributed Machine Tool Performance Models and Data Repository in New Orleans, LA. The purpose of the workshop was to 1) familiarize industry and other potential partners with the project objectives, 2) assess progress to date, and 3) identify future directions based on industrial inputs. The workshop was attended by representatives from large manufacturing companies (including Boeing, Caterpillar, Texas Instruments, and General Electric), small CAD/CAM (computer Aided Manufacturing) developers (such as N-See Software and Deneb), small metrology service companies (such as IQL and API), universities (including University of North Carolina Charlotte, University of Michigan, Arizona State, and University of Florida), national laboratories (including Lawrence Livermore, Los Alamos, and Y-12), and the U.S. Army (Watervliet Arsenal).

During the workshop, several members of APTD made presentations. Alkan Donmez presented an overview of the project, Hans Soons proposed machine tool performance data formats and information models, and Larry Welsch demonstrated the concepts involved in an experimental, World Wide Web technology-based data repository. His presentation included a demonstration of basic search and analysis capabilities of the virtual repository. The overall response was enthusiastic as indicated by requests from attendees that a consortium be formed to accelerate the project. In response to this request, the division is negotiating Cooperative Research and Development Agreements with interested companies and setting up the consortium. Moreover, a World Wide Web (WWW) home page for use by future members of the proposed consortium is being established to facilitate its work.

MEL Hosts a Power Generation and Process Industries Workshop

ISD hosted a “Power Generation and Process Industries Workshop” on Aug. 25 - 26, 1997. The workshop was cosponsored by the Fire Science Division (Building and Fire Research Laboratory - BRFL), Optical Technology Division (Physics Laboratory - PL), Processes Measurement Division (Computer Sciences and Technology Laboratory - CSTL), Physical and Chemical Properties Division (CSTL), Standard Reference Data Program, the Department of Energy (DoE) Federal Energy Technology Center, DoE Office of Industrial Technology, Electric Power Research Institute (EPRI) Instruments and Controls (I&C) Office, and the EPRI I&C Center. Nicholas Dagalakis and Maris Juberts, of ISD, organized the workshop. At the workshop, researchers in the process industries discussed and attempted to define the sensing, controls and robotic needs that are needed to improve plant operation, and reduce plant operating costs. Representatives from vendors (of controllers, sensors, etc.), manufacturers, users, and academia attended. A lengthy discussion of the needs of the users and vendors took place with topics covering measurement, sensor, control, and robotic needs of the process industries with emphasis on the electric power generation, pulp and paper, chemicals, petroleum refining, and the metal industries. The workshop concluded with several laboratory tours that were organized by the participating NIST Laboratories.

Ontology and Terminology Workshop Held

A workshop was held at NIST entitled “Terminology and Related Topics in Data and Knowledge Sharing,” cosponsored by three NIST Operating Units (MEL, BFRL, and Advanced Technology Program - ATP), DARPA, and Environmental Protection Agency - EPA. The purposes of the workshop were: 1) to present findings from the database metadata, computational lexicology, and knowledge-based ontology community; 2) to provide the background for identifying research opportunities and for developing a roadmap for the Computer Integrated Knowledge Systems effort in BFRL and in support of integration of manufacturing systems in MEL; and 3) to identify where further information sharing and/or collaboration would be useful. The results of the workshop strongly indicated that NIST is in an ideal position to bring the research community together and it was suggested that NIST initiate this by creating a web site to provide discussion on some of the unresolved issues mentioned during the workshop. The workshop was well attended with over 70 attendees including numerous representatives from industry, academia, and government.

TeamCAD Workshop Held

TeamCAD, a NIST-sponsored workshop was held at Georgia Institute of Technology on May 12-13. The theme of the workshop was Collaborative Design. The objectives of the workshop were to bring together researchers, users, and vendors doing work in the areas of collaborative design, PDM, and related CAD tools, to define the state of the art in current technology, and identify research issues. Approximately sixty people, representing universities, industry users, and software developers from both the engineering and architectural design communities attended the workshop. The workshop included two sessions of brief project descriptions, several sessions of longer research presentations, a demonstration of commercial systems, and working groups to discuss issues such as tools and practices, research challenges, and data sharing and standards. A bound proceedings volume was published, and a report based on the results of the working groups is in progress.

4th IASPM Workshop Held at NIST

The Fourth Workshop on Industrial Applications of Scanned Probe Microscopy (IASPM) was held at NIST on May 6-8, 1997. NIST, Sematech, the American Society of Testing and Materials (ASTM) E42.14 Subcommittee, and the American Vacuum Society (Nanometer Science and Technology Division) cosponsored the workshop. Of the 107 attendees this year, 31 were from NIST and the rest were from industry (vendors and users), academic institutions, and other government labs. The workshop consisted of 30 oral and 20 poster presentations. There were overview sessions on industrial applications; standards, quantitative measurements, and interpretations; and new instrumentation and techniques. There were also focused/discussion sessions in the areas of polymers and coatings, magnetic disk recording, and semiconductors.

NIST Workshop on the Exchange of Dimension Inspection Information Heavily Attended by Industry

Representatives of nineteen industrial companies gathered together with staff from the NIST Manufacturing Engineering Laboratory for the Third NIST Workshop on Modeling and Standards for the Exchange of Dimensional Inspection Information on September 8-9, 1997 at the National Center for Manufacturing Sciences in Ann Arbor Michigan. The industries represented included automotive, aerospace, heavy equipment, defense, dimensional measurement systems manufacturers, and software application developers. The workshop continued the important industry engagement in the process of developing a STEP Application Protocol for the exchange of dimensional inspection information throughout an enterprise. Workshop attendees listened to presentations by NIST staff on the STEP standardization process and the marriage between the inspection and computer domains. In addition, industry representatives worked on developing and validating inspection domain information models, defining terms and concepts in the models, and approved a draft preliminary work item. This draft version will be submitted to ISO (International Organization for Standardization) at their Florence, Italy meeting at the end of October 1997. The excellent industry participation in this effort is continuing in the virtual world by e-mail and soon by a web page and web-based discussion group.

Presentations

Smart Transducer Interface Demo at Sensors Conference

APTD, in Cooperation with IEEE's Technical Committee on Sensor Technology of Instrumentation and Measurement Society, is developing a smart transducer interface standard. A reference implementation of a draft protocol standard for digital communication between sensors/actuators and microprocessors was developed and demonstrated to the public on Oct. 22-23 at the SENSORS Conference and Exposition in Philadelphia, PA. The demonstration consisted of the integration of an NIST-implemented smart transducer object model to two smart transducer interface modules (STIM). The STIMs were developed separately, one by Hewlett-Packard, an instrumentation builder, and the other by SSI Control Technologies, a sensor producer. The proposed standard is anticipated to have a significant impact. Hewlett-Packard announced it will market an STIM development kit in the Spring of 1997.Iin support of the standard, Analog Devices Inc. revealed the design of an interface chip that implements the standard, and Boeing Aircraft Co. disclosed that it will implement the standard interface in its aircraft testing system.

PED Staff Makes Many Contributions at the 1996 Annual ASPE Meeting

Several staff members from the large scale metrology, surface and microform metrology, and the nano-scale metrology groups presented tutorials at the American Society for Precision Engineers (ASPE) meeting held in Monterey, CA, in November 1996. Chris Evans led a newly developed course on "Self Calibration: Reversal, Redundancy, Error Separation, and Absolute Testing" in cooperation with Tyler Estler and Bob Hocken of the University of North Carolina, Charlotte. Ted Vorburger and Paul Sullivan teamed up to teach the tutorial on "Surface Finish Metrology," which was being given for the sixth time at this annual conference. Clayton Teague presented two tutorials, "Basic Concepts of Precision Instrument Design--Part I on Accurate Metrology, and Part II on Repeatability." This is the 10th year that Teague has presented these tutorials. Lowell Howard presented his newly developed tutorial on "Advanced Sensors for Precision Engineering" and also presented a talk, co-authored by Fred Scire and Jack Stone, on "Fabry-Perot Interferometers for Small Displacement Measurements."

Standing Room Only at NCSL for Song's Paper on Uncertainties

The 1997 National Conference of Standards Laboratories (NCSL) was held in Atlanta from July 27 to 31. J. Song delivered a paper entitled, "The Guidelines for Expressing Measurement Uncertainties and the 4:1 Test Uncertainty Ratio (TUR)." The paper attracted an audience of about 300 people with standing room only. Its subject was the transition in the methods for calculating uncertainties. In 1988, MIL-STD-45662A, a military standard, adopted the 4:1 TUR; this was later (1994) incorporated into the American National Standards Institute (ANSI)/NCSL Z540-1 standard. However, in 1992, NIST began to adopt a new method to evaluate and express measurement uncertainties. This method uses the root-sum-of-squares (RSS) method for calculating the combined standard uncertainty from the Type A and Type B uncertainty components instead of simple arithmetic addition, and a coverage factor $k = 2$ for calculating the expanded uncertainty (equivalent to two standard deviations) instead of the three standard deviations often used in the U.S. The change from the arithmetic addition to the RSS method has reduced significantly the calculated standard uncertainties. The change of the coverage factor from k = 3 to k = 2 further reduces the calculated expanded uncertainties by 33%. In many cases, the combined effects have caused a 50% or more reduction of calculated uncertainty from the same uncertainty budget. This has been documented in calibration and measurement reports. The reduced uncertainties have also caused significant increases of the actual TUR's for the same measurement processes and tolerance ranges. For many industrial institutions, the decreased uncertainty and increased actual TUR represent an improvement of our knowledge of the measurement uncertainties, rather than an improvement in measurement quality. Therefore, when establishing the TUR for measurement quality control, the method used for calculating measurement uncertainty is an important consideration. In the paper, some examples are used to demonstrate the results of using different uncertainty methods for calculating measurement uncertainty and TUR from the same uncertainty budget.

Gage Block Intercomparison Data Presented

Data for an international intercomparison of gage blocks, which was performed late in 1996, was recently distributed to the participants. NIST was a primary participant, along with the national laboratory from the Netherlands, NKO. Four other U.S. laboratories also participated in the intercomparison sponsored by the American Association for Laboratory Accreditation, A2LA. Nine gage blocks of three different materials were measured. The sizes ranged from 1 mm to 100 mm. All laboratories performed satisfactorily. The NIST-NKO data was particularly consistent showing no evidence of length dependent errors. All NIST-NKO data agreed to better than 30 nm. 10 nm to 20 nm systematic shifts present in the data are probably a result of wringing effects and phase change corrections.

Simulation Demonstration Given at Defense Simulation and Imaging Conference

Mike Iuliano and Al Jones of MSID gave a presentation and demonstration to the Defense Simulation and Imaging Conference, May 8, 1997, at the Sheraton Crystal City, Arlington, VA. The presentation provided an overview of current simulation and virtual manufacturing projects. MSID has developed virtual manufacturing simulations of a machine shop, metal cutting on a virtual machine tool, a casting shop, and mechanical assembly line for the Black and Decker miter saw. The simulations were collaboratively developed with Deneb Robotics, Boeing, Black and Decker, and Ohio University. The machine shop and metal cutting simulations were demonstrated at the conference on Silicon Graphics newest machine, the Octane. The presentation drew a significant number of people from the conference, which was attended largely by Department of Defense (DOD) personnel and software vendors.

Manufacturing Engineering Laboratory

Office of Manufacturing Programs

The Office of Manufacturing Programs (OMP) manages cross-divisional research, other-agency-sponsored research, development, and technology transfer within the MEL. Its activities include proposal preparation and coordination, presentation to sponsors, management of funded activities, and reporting to sponsors. It plans, develops, coordinates, and reviews for quality the accomplishments and priorities of all programs and activities that involve significant interactions with the United States industrial community. It manages the National Advanced Manufacturing Testbed program to coordinate the efforts by industry, academia, NIST, and the National Laboratories to refine advanced manufacturing technologies and demonstrates approaches to distributed design, engineering, and manufacturing operations.

The National Advanced Manufacturing Testbed Program

NAMT (www.mel.nist.gov/namt/) is a research program that addresses technologies and standards for information-based manufacturing. NAMT is designed to help U.S. industry speed the transition to 21st century manufacturing capabilities. Through the NAMT program, a distributed testbed built on a state-of-the-art, high-speed computing and communications infrastructure has been developed to support collaborative research between NIST, industry, academia and other government agencies. The collaborative testbed brings together NIST scientists and engineers industry experts, academic scholars, and scientists from other government agencies to solve measurement and standards issues that impede companies and industries from making the most of their information technology. This unique collaboratory is both an Information Age workbench and showcase for demonstrating how machines, software, and people can be networked together, efficiently and effectively, to improve productivity and foster innovation at all levels of a manufacturing enterprise.

For U.S. manufacturing organizations, the NAMT offers a tremendous opportunity to pool resources and capabilities, to share risks, and, most important, to efficiently build the technical underpinnings of an advanced information infrastructure. Such a foundation of communication and computing facilities, services, and standards will yield sector wide benefits, while enabling individual companies to leverage their own information technology investments.

Researchers in MEL and other laboratories within NIST oversee the technical content of these projects. A full summary of each NAMT project is included in this section. However, a brief descriptive page on the four MEL-lead projects will also be included within the technical leading division’s section.

Characterization, Remote Access, and Simulation of Hexapod Machines

Leader: Wavering, Albert J.

Albus, James S.
Amatucci, Edward G.
Christopher, Neil
Dagalakis, Nicholas G.
Damazo, Bradley
Falco, Joseph A.
Pries, Brian
Rudder Jr., Fred F.
Russell, Robert T.
Soons, Johannes A.
Stouffer, Keith A.
Wheatley, Thomas E.

Total FTE 3.35

1998 MEL Goals, Supported

1. Laboratory research and development
3. Information-based National and International Standards and Measurements

Project Objective

To measure, extend, and demonstrate the capabilities of hexapod machines through the collaborative development and use of metrology, remote access, and simulation tools.

Needs Addressed

Rapid production of quality contoured parts requires machine tools that combine speed, accuracy, stiffness and multiaxis versatility. In addition, manufacturers look for qualities such as ease of installation and movability to enable plants to be reconfigured to meet changing market demands. A new class of parallel-actuated machine tools based on the Stewart platform mechanism presents new possibilities for meeting these needs.

However, much remains to be learned about the characteristics of these 'hexapod' machine tools before they will see widespread production application. Industry workshops have highlighted the need for:

- An in-depth understanding of the characteristics of these new machines.
- Standard test methods and measurement procedures to evaluate their performance.
- A reservoir of application experience to draw from.
- Modeling and simulation tools, for development of applications and test methods.
- Remote access capabilities, to make it easier for external collaborators to interact and participate in the work being done.
- Examination of controller and integration issues.

Technical Approach

The NAMT Hexapod project team, in collaboration with external partners, will perform work in the three areas of characterization, remote access, and simulation to address the needs discussed above. The work at NIST will be performed using the Octahedral Hexapod machine that was purchased and installed at the Gaithersburg, MD site in May 1995. To the extent possible, models, measurement techniques, and other project results will be developed in a generic form to allow them to be applied easily to other Stewart platform machines. NIST researchers are participating in a recently formed Hexapod Users Group, and plan to interact with this group to coordinate research activities and share results.

Characterization

The approach to be followed for development of performance evaluation techniques will be to use the ANSI/ASME B5.54-1992 Methods for Performance Evaluation of computer Numerically Controlled Machining Centers and ISO 230 as starting points for characterization. Modifications will then be proposed to these test procedures as necessary to make them more appropriate for hexapod machines. Performance enhancements such as improved calibration and feedback metrology techniques will also be pursued as an improved understanding of basic machine behavior is gained.

Remote Access

For remote interaction, high-speed communications links, such as ATM networks, can be used to provide real-time transfer of audio/video and sensor data to researchers at remote sites. An Internet-based version of similar capabilities will also be developed, which will provide services at a lower cost, but with some compromise in performance.

To examine controller and integration issues, an open architecture controller will be installed on the Hexapod, based on Application Programming Interfaces (APIs) and software developed under the NIST Enhanced Machine Controller (EMC) project.

Simulation

From the validation of machine motions to detailed investigation of the errors and structural dynamics of the Hexapod, a comprehensive set of modeling and simulation tools is needed to reduce the risks and increase the effectiveness of the hexapod research efforts. These simulation capabilities will be developed in an incremental fashion, gradually adding to the fidelity and detail of the modeled behavior.

Web-based access to some of these animation and simulation tools will be explored as a means for providing potential new partners with an opportunity to gain familiarity with this new machine tool technology.

Prior Year Accomplishments

- Published and presented results at several meetings; participated in numerous demonstrations for industry, government, and university visitors.
- Surveyed European hexapod machine tool research activities by attending the EMO machine tool trade fair, visiting the Aachen University of Technology and the Fraunhofer Institute, and participating in the first meeting of the European Hexapod User Group.
- Ohio State University performed model identification experiments on the test strut and experimentation with a prototype strut microactuator. University of Maryland combined their part placement software with the stiffness model they developed, performed some modal analysis and preliminary structural dynamics testing.
- Demonstrated that substantial accuracy gains can be achieved through ball-bar based calibration of the Hexapod.
- Performed experiments with laser measurement system on the test strut. Demonstrated the feasibility of mounting the laser outside the strut and measuring down both sides to compensate for Abbe error.
- Developed VRML models and digital movies of the Hexapod machine, and contributed to virtual environment implementation.
- Machined 45 detector rails for NIST time-of-flight spectrometer (perhaps the first use of a hexapod machine to make parts to be used in service).
- Implemented basic EMC controller for test strut, demonstrated driving hexapod simulation from controller, and integrated controller with MSID NAMT Framework.
- Hosted Second Hexapod User Group Meeting

FY 1998 Plans

- Participate in ASME IMECE Hexapod Machine Tool Panel Session and Hexapod User Group Meetings. (ISD, PED, APTD)
- Implement improved audio, video, and sensor remote access capabilities. (ISD)
- Implement web-accessible modeling and simulation tools. (ISD)
- Make full machine “open architecture-ready” and install ATR RCS controller on test strut. (ISD, ATR)
- Exercise MSID Framework integration using TEAM or similar test parts. (MSID, ISD, FTD)
- Conduct B5.54 machining performance tests. (ISD, FTD, PED, APTD)
- Install and test prototype strut position feedback system on one strut of Hexapod. (ISD, PED, APTD)
- Finalize strut feedback metrology system design. (ISD, PED, APTD)
- Perform laser ball bar tests. (APTD)
- Continue development and testing of calibration techniques. (APTD)

Five Year Plan Goals vs. Fiscal Year

1998 Develop error model and error budgeting techniques for parallel machines

1999 Develop techniques to measure and/or estimate parametric errors

1999 Implement ATR controller and integrate with MSID Framework

2000 Implement web interface to Hexapod simulation tools and experimental data

2000 Develop feedback metrology enhancements

2001 Perform machining tests of complex parts

2001 Provide input to B5 and ISO 230 standards committees

2001 Implement controller enhancements (e.g., thermal comp., part probing, advanced control algorithms)

Standards & Measurement Services

Standards Committees:

Hexapod Users Group
(informal pre-standard group)

Computing and Communications Infrastructure

Leader: Densock, Robert J.

Staff: Fowler, Deborah Nickerson
Stieren, Dave C.

Total FTE 0.75

1998 MEL Goals, Supported

1. Laboratory research and development.

Project Objective

Provide a distributed, multimedia, computing and communications infrastructure that is needed by the NAMT projects. The Infrastructure includes: 1) state-of-the-art computing capabilities needed by the NAMT projects; 2) a leading-edge, high-speed communications network to connect the NAMT project sites (internal and external); 3) a suite of multimedia collaborative software; 4) a multipurpose laboratory at NIST that is used by NIST researchers and collaborators to work on NAMT projects.

Needs Addressed

As manufacturing enterprises become more distributed, there is a need for robust computing and communications infrastructures that integrate voice, video, and data services as a means of pulling the pieces of the distributed enterprise closer together. Today, different types of special purpose networks are used to build infrastructures. Telephone networks are used to carry voice traffic. Closed circuit TV networks are used to carry video. Packet switching networks, like the Internet, are used to carry computer data traffic. In the future, high-speed networks will be used to integrate voice, video and data traffic over a single physical network and bring these multimedia services to the desktop. The NAMT has built an integrated multimedia infrastructure to examine and exploit its capabilities to benefit U.S. manufacturing.

Technical Approach

The high-speed NAMT network was constructed using Asynchronous Transfer Mode (ATM). ATM is a new network technology that combines the best features of circuit-switched networks (like the telephone network) and packet-switched networks (like the Internet) and was built from the ground up to carry voice, video and data traffic. Unlike traditional Local Area Networks (LANs) that share the available bandwidth among all the attached users, ATM dedicates bandwidth to each user. This dedication of bandwidth allows users to send voice and video traffic without delays imposed by other heavy network users. The NAMT ATM network currently spans nine buildings at NIST and connects ATM-attached workstations & servers,

Ethernet switches (used to provide connectivity to less demanding workstations), and audio/video encoders and decoders that enable TV quality audio and video across the ATM network. In outer years, the ATM network will be expanded to reach external collaborators via the ATDnet (an experimental Washington area ATM network) and the NGI (The Next Generation Internet that will connect over 100 Government locations nationally) to test the effectiveness of ATM in the wide-area. NAMT workstations include a variety of Sun, SGI, and PC computers that provide access to a wide variety of manufacturing

applications and provide desktop video conferencing capabilities across the network. The NAMT Lab is a multi-purpose computer room that can be used for daily research, meetings, training sessions, demonstrations, etc. The lab contains a 90” video wall that can display NAMT lab computers or real-time audio and video from any of the NAMT project sites. It serves as the window into the NAMT and is used to demonstrate the integrated, distributed manufacturing environment has been put in place.

Prior Year Accomplishments

- Designed and pilot installed interactive, ATM-based, conferencing capability between NAMT sites.
- Installed and configured several new NAMT workstations.
- Expanded fiberoptic ATM backbone network to five additional buildings at NIST.

FY 1998 Plans

- Extend NAMT infrastructure capabilities to NIST auditoriums to enable large, interactive NAMT demos.
- Assist with demos utilizing NAMT resources and assure smooth operation of NAMT facility.
- Conduct annual requirements analysis to determine FY97 hardware purchases.
- Increased attention towards testing collaborative software tools for use in NAMT.

Five Year Plan Goals vs. Fiscal Year

1998 Extend NAMT infrastructure capabilities to NIST auditoriums.

1998 Install new infrastructure capabilities requested in FY98.

2002 Increase the number of communication links to external testbeds in support of distributed manufacturing research and related standards development

2002 Migrate proven computing, networking, and collaboration technologies to the desktop of NIST researchers

2002 Upgrade the design of other NIST computing labs based on the NAMT design in order to allow cooperative research among the NIST laboratories

Design, Manufacture, and Calibration of Brachytherapy Sources

Leader: Soares, Christopher (PL)

Staff: Amatucci, Edward G.
Colle, Ronald (PL)
Coursey, Bert (PL)
Densock, Robert J.
Karam, Lisa (PL)
Mourtada, Firas (PL)
Norcross, Richard J.
Seltzer, Stephen (PL)
Unterweger, Michael (PL)
Wheatley, Thomas E.
Zimmerman, Brian (PL)

Total FTE 3.0

1998 MEL Goals, Supported

1. Laboratory research and development.
2. Physical-based National and International Systems of Standards and Measurements.

Project Objective

To develop techniques that improve the manufacture of radioactive sources used by the medical community in radiation therapy procedures for cancer and heart disease patients, ultimately to help improve the efficacy of these treatments.

Needs Addressed

Brachytherapy is a form of medical treatment where a radiation source, or seed, is placed near or within the lesion. Brachytherapy procedures are performed at an approximate rate of 50,000 per year primarily in the treatment of cancer, and very recently in the prevention of vascular restenosis after balloon angioplasty. The recent interest in the use of brachytherapy to prevent post-angioplasty restenosis represents an enormous potential growth, as restenosis occurs in 30%-50% of the roughly 500,000 balloon angioplasties that occur annually. There is a great deal of opportunity to improve the manufacturing processes for these radioactive seeds, including the following areas: a more accurate prediction capability for dose distribution from a proposed source design is needed; better control of source quality during manufacturing is necessary; and improved and expanded dosimetry standards and measurement methods are needed to provide traceable dosimetry calibrations. This project is addressing these needs in various capacities.

Technical Approach

This project is working to provide the information-based tools that are necessary to ensure that the end product matches the designed product by providing interfaces to standard simulation codes for predicting source output from design input. The project is facilitating on-line measurement techniques to ensure quality during source manufacturing. Both of these efforts are aiming to increase the quality of manufactured sources in terms of both uniformity and reproducibility. Additionally, new dosimetry standard reference materials and calibration methods are being developed to help monitor source quality during fabrication, as well as to be responsive to new and evolving sources. Finally, the project is developing remote, fully automated calibration facilities and correction matrix data for user measurements to further advance the manufacturing processes.

Prior Year Accomplishments

- Conduct of international workshop on Intelligent Systems Approaches to the Design, Manufacture, and Calibration of Radioactive Sources for Brachytherapy.
- Initial design of automated film handling system.
- Construction of prototype automated source transfer system.

- Development of calibration transfer methods.
- Development of brachytherapy beta-source calibration service.
- Acquisition and testing of measurement stations.
- Development, installation, and testing of dosage prediction calculations.

FY 1998 Plans

- Generate measurement system correction matrices.
- Continue development of standards and measurement methods.
- Construct and characterize manufacturing SRMs.
- Construct simulation code front ends.
- Demonstrate prototype remote calibrations.
- Extend network between NAMT Laboratory, NIST source calibration laboratory, and selected collaborators

Standards & Measurement Services

SRM:

Will be developed during Fiscal Year 1998.

Calibrations:

Remote calibration method planned for Fiscal Year 1998

Development of Machine Tool Performance Models and a Machine Data Repository

Leader Donmez, Alkan

Staff: Borchardt, Bruce R.
Estler, W. Tyler
Falco, Joseph A.
Frechette, Simon P.
Gilsinn, David E.
Iuliano, Michael
Jones, Albert T.
Lee, Yung-Tsun Tina
Ling, Alice V.
Phillips, Steven D.
Sawyer, Daniel S.
Soons, Johannes A.
Wavering, Albert J.
Welsch, Lawrence A.
Wilkin, Neil D.

Total FTE 3.46

1998 MEL Goals, Supported

1. Laboratory research and development
3. Information-based National and International Standards and Measurements

Project Objective

In cooperation with industry and academia, to create a virtual manufacturing environment to simulate the complete manufacturing cycle so as to reduce the time for new product introduction.

Needs Addressed

To reduce design and production cycles, manufacturers need robust tools to predict their manufacturing capabilities before they start manufacturing prototypes for new products. The conventional sequence of operations starts with the raw stock of material and the design information. From these pieces of information, a process plan is developed that takes into account capabilities of available machines tools. Parts are then manufactured and inspected on CMMs to verify conformance to the specifications. Based upon verification results, design, or manufacturing plans or specifications are modified and the process is repeated. Several iterations may be required. Prototyping is a very costly effort, since, in general, the outcome cannot be predicted with existing design and analysis tools. Virtual manufacturing, which involves a complete simulation the total manufacturing cycle, including verification, presents a unique opportunity for industry to reduce the time needed for new product introduction.

Technical Approach

A major challenge in creating a virtual manufacturing environment is the representation of the performance and capabilities of various machine tools. The resulting part geometry's when these machine tools are used to produce parts and CMMs are used to inspect the parts. Currently, there are no provisions in machine tool or CMM standards to store the performance information in any electronic media. The lack of standard representation prevents the creation of machine data repositories that are needed to test different simulation algorithms and to compare the performance of a given machine against many other machines within a similar category. In order to overcome this problem, in cooperation with industry and academia, first a standard format for representing meaningful machine tool performance data is being developed. It includes provisions for storing information such as error notation, sign conventions, axis designations, machine structural descriptions etc.. Once the format is evaluated for its applicability, a data base structure will be developed to accommodate this data format. In the next step, machine tools at NIST, and at the facilities of project collaborators, will be characterized to obtain the data needed to populate the repository.

In addition, remote access mechanisms will be developed to allow access by project participants located at various sites.

Prior Year Accomplishments

- Investigation of incorporating machine tool and CMM performance uncertainties into models was initiated
- Another Web site to facilitate communication among consortium members was developed
- An experimental Web based repository was developed and demonstrated
- An industry/academia consortium was established
- The CAD representation of turned parts was improved visualizing the errors in various radial directions
- Preliminary information models for circularity tests were developed
- An initial data dictionary with more than 250 entries was developed
- Preliminary data formats were developed and presented in the workshop
- An industrial workshop was held in February 97.

FY 1998 Plans

- Continue investigation of incorporating inspection analysis tools into the repository
- Initiate the development of machine tool performance tracking tools
- Continue development and improvement of simulation tools to represent actual machine behavior
- Continue development of information models for additional machine performance tests
- Initiate development of machine diagnostic tools to be incorporated into the repository
- Develop graphical display tools for data stored in the repository
- Improve file uploading/downloading capabilities of the repository
- Develop a Web page to extract attributes of machine tool circularity tests
- Develop a tree structure for the Data Dictionary
- Update Data Dictionary with additional entries

Five Year Plan Goals vs. Fiscal Year

1999 Continue development of Data Dictionary

1999 Continue development and improvement of the repository

1999 Incorporate data analysis tools into the repository

1999 Incorporate modeling tools into the repository

1999 Incorporate performance tracking tools into the repository

2000 Develop and incorporate inspection analysis tools into the repository

2000 Develop new test methods and associated data analysis tools

2002 Develop dynamic models of machine tools and incorporate them into the repository.

2002 Integrate machining process models into the repository

Standards & Measurement Services

Standards Committees:

Working with the Machine Tool Performance Evaluation Standards community, both Nationally and Internationally, to inform these committees about the upcoming information technology tools on machine tool testing to eventually incorporate these tools into their standards.

Framework

Leader: Christopher, Neil

Staff: Barkmeyer, Edward J.
Flater, David W.
Frechette, Simon P.
Harary, Howard H.
Messina, Elena
Proctor, Frederick M.
Sauder, David A.
Scott, Harry A.
Vorburger, Theodore V.
Wallace, Evan K.
Welsch, Lawrence A.

Total FTE 3.55

1998 MEL Goals, Supported

1. Laboratory research and development
3. Information-based National and International Standards and Measurements
4. Internal Management: improve the management of technical programs including planning, prioritization, direction, and delivery of results.
5. Customer satisfaction and program recognition

Project Objective

Accelerate the establishment and adoption of standards for distributed manufacturing systems through the implementation, testing, and analysis of emerging open industry specifications.

Needs Addressed

Information technology is consuming an increasing share of industry budgets for manufacturing systems. Manufacturers attempt to gain competitive advantage by supporting their operations with “best-in-class” manufacturing software components and information infrastructures. System costs can be reduced by adopting consensus models of information, software component interface definitions, and information exchange mechanisms. The rate of information technology change and the large variety of available technology increases the risk that adoption of information technology will not result in competitive advantages for manufacturers. Information that results from the testing of emerging technologies can be used to reduce the risks associated with technology adoption. Adoption of new business models reveal a tendency for manufacturing customers and suppliers to integrate information systems along supply chains. Analysis of the interrelationships among standards helps to uncover standards-based approaches to integration of enterprise systems and processes.

A number of national consortia are working to develop standards and protocols that address parts of the overall open distributed systems problem facing the manufacturing industry. The NAMT Framework project has been asked by these consortia to contribute to this national effort by implementing, testing, and analyzing standards and protocols for manufacturing information systems. It is expected that the results of this project, when fed back to the consortia, will accelerate specification development and that the results, fed forward to the standards community, will accelerate industry consensus.

Technical Approach

The approach taken by the NAMT Framework project is to establish a process, system, and tools for testing, emerging pre-standard, industry specifications. The process is to work with a set of industry consortia and standards organizations to identify specifications that are open, that contain elements appropriate for standardization, and that are defined well enough to be the basis for prototype implementations. These specifications are then implemented as prototypes in the NIST laboratory environment and tested with production test data against a manufacturing scenario that operates physical and simulated manufacturing devices. The results of the implementation and testing form the basis for documented reviews of the specifications. These reviews address the internal consistency of each specification as well as the technical relationships between the specifications. These reviews are used as input to ongoing development within the various consortia and they are used in the formal consensus-building process within standards organizations. Information resulting from prototype implementation, testing and analysis of manufacturing information systems standards to explore issues such as component compatibility, system performance, and scalability will help to reduce the risk associated with technology adoption.

The NAMT Framework has begun its work on specifications emerging from SEMATECH, the Rapid Response Manufacturing (RRM) consortium, the Technologies Enabling Agile Manufacturing (TEAM) initiative, the National Industrial Information Infrastructure Protocols (NIIIP) program, the Object Management Group (OMG), ISO 10303 Dimensional Inspection Data Exchange, and Standard Data Access Interface (SDAI). The project also incorporates prior research performed at NIST including the Manufacturing Systems Integration (MSI) project, the Enhanced Machine Control (EMC) project, the Next Generation Inspection System (NGIS) project, the Quality In Automation (QIA) project, and the Systems Integration of Manufacturing Applications (SIMA) program.

The system used to exercise these various specifications consists of manufacturing software applications ranging from Electronic Commerce (EC) Applications, through Enterprise Requirements Planning (ERP), Manufacturing Execution Systems (MES), and machine control. The Framework test system also implements and examines underlying communication software (e.g., CORBA, JAVA, Active-X, and DCOM), heterogeneous computer platforms and operating systems, an Asynchronous

Transfer Mode (ATM) based network infrastructure, and physical manufacturing equipment. The current applications are those typically used by production operations including: a shop controller, an inspection workstation controller, a product data management system, an object-oriented database, a simulation system and an interface for monitoring system operations. The current scenario focuses on inspection operations and the test data is for machined metal parts. Future work includes concurrent use of different control specifications, further examination of application programming interfaces, further development of manufacturing information models, examination of real-time communications specifications, and scheduling operations. In addition, planned work calls for extending the scenario to include more robust inspection operations, machining operations, and control of simulated workcells.

Related Developments

- The new NAMT Internet Commerce for Manufacturing project is collaborating with the NAMT Framework project to provide an analysis of the integration of manufacturing electronic commerce operations with manufacturing enterprise requirements planning operations.
- The Manufacturer's CORBA Interface Testing Toolkit (MCITT) is software that facilitates, accelerates, and automates testing of the behavior, performance, scalability, and conformance of software components based on the Common Object Request Broker Architecture (CORBA). MCITT is being developed by the Framework project for public release due to its wide applicability in testing manufacturing software.
- The Advanced Process Control Framework (APC) evaluates the interfaces between process control and Manufacturing Execution systems. This project is integrating an instance of the prototype APC Framework into the NAMT Framework Test System.
- The Software Engineering Institute is collaborating with the Framework project to evaluate software component interaction protocols (e.g. CORBA, ActiveX, DCOM, and JAVA) under varying conditions such as real-time manufacturing.

- The Enterprise Requirements Planning Project (ERP) is creating an activity model for ERP operations that will be the basis for Framework project participation in the Object Management Group, Manufacturing Domain Task Force.
- The NAMT Hexapod Project is providing the Hexapod control software that is being integrated into the NAMT Framework Test System. This is useful in demonstrating a scenario which implements complex combinations of manufacturing protocols.
- The Manufacturing Enterprise Integration Project is working through ISO TC184/SC5/WG1 to standardize a General Enterprise Reference Architecture (GERAM) which will be useful in representing the scope of the Framework project from Electronic Commerce through Enterprise Requirements Planning, Manufacturing Execution, and Machine Control.

Prior Year Accomplishments

- Developed a software test tool to evaluate implementations of the OMG Common Object Request Broker (CORBA) performance characteristics under real-time manufacturing constraints and conducted testing using NIST developed controller software.
- Integrated the Production Information Base to the Framework Manufacturing Execution System (SEMATECH CIMF)using a STEP SDAI (ISO 10303 part 26) binding to CORBA.
- Developed and integrated a new graphical user interface that displays message passing between Framework components.
- Integrated the Framework Manufacturing Execution System (SEMATECH CIMF) to the Hexapod Machine tool controller (driving a simulation of the NIST Hexapod).
- Collaborated in the development and review of the SEMATECH Computer Integrated Manufacturing Application Framework versions 1.4, 1.5, and 2.0.
- Held industry workshop 9/97 to refine inspection information models and develop industry consensus on preliminary work item submission to ISO.
- Tested the behavior of the ISO STEP Part 26 (SDAI) interface implementation and tested the behavior of the Product Data Management interface implementation using MCITT.
- Co-developed, in conjunction with the Advanced Process Control Framework Project, the Manufacturer's CORBA Interface Testing Toolkit (MCITT) prototype.
- Established on-line repository for industry collaboration on the development of inspection information models.
- Developed and published activity models for inspection processes.
- Held an industry workshop 4/97 to develop requirements and information models for the inspection process.
- Implemented the ISO 10303 and SDAI binding to CORBA and publish the experience report.
- Demonstrated the operational and functional characteristics of the NAMT Framework distributed manufacturing system to industry, government and university stakeholders.

FY 1998 Plans

- Host a Manufacturing Electronics Commerce track at the 1998 NIST Manufacturing Conference.
- Collaborate with the NAMT Internet Commerce for Manufacturing on development of a business test case scenario that identifies activities and information flows shared by Electronic Commerce (EC) and manufacturing Enterprise Requirements Planning (ERP) applications.
- Implement and test the models of inspection information using the Framework test system.

- Integrate the Hexapod online control program editing software to the Framework Product Data Management software.
- Integrate control of a physical Hexapod strut to the Framework Manufacturing Execution System.
- Publish the results of the real-time Common Object Request Broker Architecture testing tool and evaluations.
- Work with the OMG Manufacturing Domain Task Force to develop a Request for Information to determine the requirements for Enterprise Requirements Plannning system interface standards.
- Work with members of the Object Management Group, Manufacturing Domain Task Force to develop an industry whitepaper outlining the scope of work efforts in Enterprise Requirements Planning system standards.
- Develop a NIST/MEL response to the OMG request for information on Manufacturing Execution System and Machine Control interfaces. The NIST response will represent input from several projects, technical groups, and divisions in MEL.
- Work with other OMG Manufacturing Domain Task Force members to develop and issue a Request for Information (RFI) on issues regarding standardization of Manufacturing Execution Systems(MES)and Machine Control (MC)interfaces.
- The OMG Manufacturing Domain Task Force will adopt a "joint revised proposal for standard PDM interfaces" by June 1998. Framework Project Staff will participate in the formal reviews and recommendations for final revisions.
- Submit to ISO TC184/SC4/ for review, a preliminary work item for the standardization of inspection information models.
- Identify industrial partners from ISO TC184/SC4/ member countries to participate in development of inspection data exchange standard.
- Develop a plan that demonstrates issues and potential standards solutions regarding interfaces between Manufacturing Electronic Commerce systems and Manufacturing Enterprise Requirements Planning systems.
- Hold several workshops to refine information information models, refine inspection activity models for ISO TC184/SC4 standardization and implement inspection information models for applications testing of pre-standard models.

Five Year Plan Goals vs. Fiscal Year

1999 Establish a baseline manufacturing activity and information model, using a common set of assumptions and constraints, that spans manufacturing operations from Electronic Commerce, to Enterprise Requirements Planning, to Manufacturing Execution Systems to MachineControl.

1999 Implement and test the OMG standard for Product Data Management (PDM) interfaces in the Framework Test System.

1999 Integrate and test the physical Hexapod machine tool controller with the NAMT Framework Manufacturing Execution System.

2000 Work with industry to create, through ISO TC184/SC4/WG3, an international standard for models of inspection information.

2000 Work with industry to create, through OMG Manufacturing Domain Task Force, international standards for Manufacturing Execution System (MES) interfaces.

2000 Work with industry to create, through OMG Manufacturing Domain Task Force, international standards for Enterprise Requirements Planning (ERP) interfaces.

2001 Integrate and test the NAMT Framework Test System in a multi-facility, distributed manufacturing system pilot.

2002 Using the baseline manufacturing model as a reference, create a parallel set of models that support next generation manufacturing operations such as biotechnology manufacturing and nano-manufacturing.

2002 Integrate simulations of next generation manufacturing system such as nano-manufacturing into the Framework Test System.

2002 Integrate physical next generation manufacturing systems such as nano-manufacturing process control systems into the Framework Test System

Standards & Measurement Services

Committees:

- ISO TC184/SC4/WG3, Product Modeling, on the standardization of the models of inspection information.
- Object Management Group, Manufacturing Domain Task Force, Enterprise Requirements Planning Working Group (Co-Chair).
- Object Management Group, Manufacturing Domain Task Force, Manufacturing Execution System and Machine Control Working Group.
- Object Management Group, Real-time Special Interest Group.
- SEMATECH CIM Applications Framework, Architecture and Integration Committee.
- SEMATECH CIM Applications Framework, Specification Management Committee.

Interface Data Standards for Real-Time Construction Site Metrology

Leader: Stone, William (BFRL)
Chang, Peter (BFRL)
Densock, Robert J.
Goodwin, Kenneth R.
Jacoff, Adam S.
Pfeffer, Lawrence (BFRL)
Proctor, Frederick M.
Reed, Kent A. (BFRL)

Total FTE 3.0

1998 MEL Goals, Supported

1. Laboratory research and development
3. Information-based National and International Standards and Measurements

Project Objective

Develop a better understanding of current and emerging metrology and automation technologies for construction applications, and develop data standards required to effectively communicate metrology and site simulation information to, from, and within construction job sites.

Needs Addressed

U.S. construction industries account for approximately 13% of this country's gross domestic product. Time is the primary issue in these industries, and even small construction technology improvements that enable the ability to finish a job correctly the first time and on-time offer the potential for major economic impact to this very significant industry. Real-time wireless metrology capabilities form the foundation for industry's abilities to automate and improve the operations of construction sites. This project is working with industry to speed the development and application of the standards required implementing real-time metrology into automated construction site applications.

Technical Approach

The project is establishing a National Construction Automation Testbed for collaborative development with industry of interface data standards for real-time construction site metrology. This remotely accessible testbed facility is being developed within the NIST NAMT program. The testbed will incorporate site simulation tools for the planning and programming of semi-automated machinery into the development of the interface data standards that are the primary focus of the project. The testbed will be conducting construction experiments at full-scale to determine problem areas for information transfer.

Prior Year Accomplishments

- Productive inter-Laboratory NIST team established between BFRL and MEL to address construction automation.
- Several conference papers and research reports published.
- Industry workshop on construction site integration standards held at NIST in the NAMT Lab.
- Site visits to industry, university, and federal labs conducted.
- National Construction Automation Testbed at NIST more than 50% configured for tests of wireless uplink packet protocols for rigid body construction components.

FY 1998 Plans

- Continue development of job site models.
- Continue development and testing of NIST National Construction Automation Testbed.
- Develop an initial specification for wireless remote jobsite data packets for rigid body components.

Standards & Measurement Services

Standards Committees:

Chairmanship of ASCE Committee on Field Sensing and Robotics.

Internet Commerce for Manufacturing

Leader: Goldstein, Barbara (EEL)

Staff: Barkmeyer, Edward J.
Brady, Kevin (EEEL)
Christopher, Neil
Flater, David W.
Fong, Elizabeth (ITL)
McCaleb, Michael (EEEL)
McLay, Michael (EEEL)
Nell, Jim G.
Parks, Curtis (EEEL)
Rhodes, Thomas (ITL)
Rosenfeld, David
St. Pierre, James (EEEL)

Total FTE 3.0

1998 MEL Goals, Supported

1. Laboratory research and development.
3. Information-based National and International Standards and Measurements

Project Objective

Goods and services traded over the Internet will reach a total value of $327 billion by 2002, according to a recent report from Forrester Research in Cambridge, Mass. The objective of the Internet Commerce for Manufacturing (ICM) multi-lab project is to model how the manufacturing industry, through open systems and standards, might participate in this market growth and take advantage of the benefits of Internet-based commerce. This project will work with industry to create an environment where small manufacturers of mechanical and electronic components may participate competitively in virtual enterprises that produce large manufactured systems. In particular, this project will identify and overcome some of the manufacturing information technology problems that exist at the intersection of manufacturing and electronic commerce systems.

This project will demonstrate a prototype system that combines business processes, manufacturing practices and enterprise operations with electronic commerce services, and is built upon open, distributed systems technology. This work contributes to the standards development process by supporting and testing selected emerging industry standards, and by working to achieve consensus across standards efforts that share common notions of business process, manufacturing operations, and enterprise planning. Furthermore, the proposed work includes several workshops to examine the architectural issues that impact the creation of systems that combine manufacturing operations with business processes in an open, distributed network environment.

Needs Addressed

The beneficiaries of this project are small and medium sized manufacturers of mechanical and electronic components, the large manufacturers of complex systems that incorporate these suppliers into their processes, and software vendors of manufacturing execution systems, enterprise requirements planning systems, and electronic commerce software solutions. This project responds to needs expressed by industry for both efficient technical data exchange, and the ability to link the flow of technical information with their business transactions. For example, the National Electronics Manufacturing Initiative's (NEMI) 1996 National Electronic Manufacturing Roadmaps points to the lack of interoperability among applications as one of the greatest barriers to change for that industry, and has identified supply chain integration as a major goal within its Five-Year Plan.

Technical Approach

This project proposes a comprehensive approach to addressing issues of concern to the manufacturing community. The technical approach includes working with industry, academia, and standards development organizations to identify a cogent, manufacturing-electronic commerce, business case, modeling activities and data flows, reviewing standards and architectural protocols, developing a test case scenario, implementing a demonstration system, hosting periodic workshops, and participating in standards development processes. This project will establish a prototype, pilot system, demonstration that combines a baseline technical interchange demonstration with a suite of business transactions. The technical interchange demonstration will focus on the flow of information among various organizations needed to produce a Printed Circuit Assembly (PCA). The project will leverage off of existing industry work and ongoing efforts to piece together a data interchange scenario as the circuit board goes from design through assembly, and perhaps through distribution and retail.

This project will marry a technical interchange demonstration with a suite of business transactions that support integrating small manufacturers of mechanical and electronic components into a larger supply chain that produces more complex manufactured goods. While the exact partitioning of business processes is expected to follow from the Scenario Workshop and Business Case, the following functions will likely be included in demonstration: · Supplier identification and certification · Negotiation and settlement · Security and firewall service.

The following standards and products are expected to contribute to the business interchange: · Object Management Group (OMG) specifications, such as those emerging from the Electronic Commerce and Manufacturing task forces; · EDI-related standards, such as those emerging from the Electronics Industry Data Exchange Association (EIDX); · EDI-related products, such as IBM's EDI/Domino product in development, based on the National Industrial Information Infrastructure Protocols (NIIIP) results. Initially, the project will evaluate the eCo System framework from CommerceNet as an architectural baseline, as well as relevant standards from organizations such as OMG and W3C. The project will also leverage existing work developed by EEEL and MEL researchers that resulted in manufacturing operational capability that could be used in the test case implementation. In particular, elements of EEEL's Infrastructure for Integrated Electronic Design (IIED) and Infrastructure for Integrated Electronic Manufacturing (IIEM) and MEL's NAMT Framework for Discrete Parts Manufacturing will be leveraged into this project.

Prior Year Accomplishments

- Demonstrated definition development.
- Procured project partner organizations.
- Defined project scope and plan development and refinement.

FY 1998 Plans

- Project Management, Reporting, and Technology Transfer: Ongoing periodic deliverables throughout fiscal year 1998
- Manufacturing Electronic Commerce Standards Participation
- Manufacturing Electronic Commerce Test Case Demonstrator Implementation
- Manufacturing Electronic Commerce Systems Analysis and Architecture Development Document
- Manufacturing Electronic Commerce Workshops
- Manufacturing Electronic Commerce Implementation Test Case Scenario Document
- Manufacturing Electronic Commerce Standards Roadmap Document
- Manufacturing Electronic Commerce Activity Analysis and Modeling Document
- Manufacturing Electronic Commerce Business Case Analysis Document

Standards & Measurement Services

Standards Committees:

The following represent standards activities that could benefit or be the recipients of this project's research, and project staff will be active in these standards bodies/committees: Object Management Group (OMG) Manufacturing and Electronic Commerce Domain Task Forces, the ISO Electronic Data Interchange (EDI) suite of standards, the Institute for Interconnecting and Packaging Electronic Circuits (IPC) GenCAM standard, and the Surface Mount Equipment Manufacturers Association (SMEMA) Standard Recipe File Format (SRFF)

Nanomanufacturing of Atom-Based Standards

Leader: Vorburger, Theodore V.

Staff: Allen, Robert H.
Damazo, Bradley
Fu, Joseph
Land, Janet L.
Monk, David (EEEL)
Nidamarthi, Sriniva
Osti, Manfred
Pellegrino, Joe (EEEL)
Rhorer, Richard
Russell, Robert T.
Silver, Richard M.
Sriram, Ram D.
Stouffer, Keith A.
Swyt, Dennis A.
Wheatley, Thomas E.

Total FTE 3.80

1998 MEL Goals, Supported

1. Laboratory research and development.
2. Physical-based National and International Systems of Standards and Measurements
3. Information-based National and International Standards and Measurements

Project Objective

To support the development and deployment of the technology of: (1) fabrication and use of nanometer-scale, dimensional artifacts at geographically-distributed sites; (2) computer modeling, simulation, and prototyping of mechanical systems and components, including an artifact transport system for transporting critical artifacts between two or more sites in a highly-controlled environment; (3) remote telerobotic operation of scanned probe microscopes; and (4) links between sites by advanced computers and communications for high-speed video, voice, and data transmission among collaborating institutions in industry, government, and academia.

Needs Addressed

According to industry trends projected in the Semiconductor Industry Association's National Technology roadmap; the critical dimensions of microelectronic devices will be near 100 nm within a decade, requiring dimensional standards with uncertainties near one nanometer and a degree of geometric perfection near to that of an ideal atomic lattice. As a result, NIST is undertaking development of atom-based, dimensional standards, where feature size and geometry derive directly from that of the atomic lattice. Some such physical standards will need to be fabricated, transported, and used at different sites, spending their lives under vacuum or other highly-controlled environments. Microelectronic devices themselves have a similar production cycle wherein expensive specialized equipment carry out different steps of the overall manufacturing process at different manufacturing sites. Such manufacturing steps include research and development, design, fabrication, inspection, processing, or repair. Many of these steps strongly depend upon sophisticated computer modeling, communications, and control.

Technical Approach

The project aims to: (1) demonstrate the feasibility of fabricating calibration standards with nanometer-scale dimensions for step-height, linewidth, and grid geometry where the size and geometry of the features is determined by atomic dimensions and crystal lattice properties by using controlled natural processes such as lattice dislocations; (2) develop a standardized-interface, portable, artifact transport system to allow physical transport under vacuum of wafers and other substrates undergoing processing in high-vacuum systems in clean-room facilities at geographically-different locations; (3)demonstrate remote diagnostic operation of scanned probe microscopy systems using standard data representations and controller interfaces.

Prior Year Accomplishments

- Published article in Applied Physics Letters on the silicon step height artifacts.
- Designed modifications of MBE exit/entry chamber for interfacing with the artifact transport system.
- Fabricated a variable-strain InGaAs/GaAs lattice-based grid artifact by molecular beam epitaxy (MBE)
- Developed and installed the DOE2000 code on the Nano-scale Metrology Group SEM
- Received delivery of the Topometrix SPM with a new tuning fork probe
- Implemented CommerceNetAIMS server, a software environment that encourages collaborative design, on our system at NIST.
- Simulated the ATS operation as well as its assembly sequence on a high end graphics (SGI) workstation.
- Represented the ProE model of the Artifact Transport System (ATS) in a neutral format (VRML) so that individual team members can view the model on their own workstation
- Conducted workshops of industrial user groups in two areas: the laboratory intercomparison of single atom step-height standards and SPM image and control standardization
- Designed an ultrahigh vacuum Artifact Transport System (ATS).
- Drafted a formal project definition document based on results of the external project review
- Fabricated and measured a Si single-atom step-height specimen, the prototype of one kind of atom-based dimensional artifact

FY 1998 Plans

- Publish three reports or articles related to this project.
- Fabricate InGaAs/GaAs uniformly strained heterostructure as a two-dimensional grid artifact.
- Develop CommerceNetAIMS software into a useful collaborative design tool for team members and use the ATS design and fabrication as a test bed to explore how well team members work collaboratively.
- Develop assembly simulations that are platform-independent and operating system-independent. Explore possible creation of standards in this area.
- Modify the DOE200 code and coordinate our efforts with the University of North Carolina
- Draft a specification for shared data files for an SPM
- Complete the laboratory intercomparison measurements of the silicon single-atom step-height specimens
- Complete fabrication of and demonstrate the artifact transport system, including a built-in data-logging capability
- Establish a CRADA with firms served by this project
- Test the motion control and interface for telerobotic operation of a prototype SEM, STM, or SPM

Five Year Plan Goals vs. Fiscal Year

1998 With industrial partners, develop first draft specifications for telerobotic controller interfaces.

1998 With industrial partners, develop first draft specifications for properties of and measurement methods for characterizing atom-based dimensional standards.

1998 Manufacture and measure an atom-based dimensional standard in UHV STM.

1998 Demonstrate operation of artifact transport system on "wheels."

1999 With industrial partners, develop first draft of specifications for artifact transport system

1999 Demonstrate simulation of telerobotic operation of SPM

2000 Demonstrate telerobotic operation of SPM

2002 Demonstrate distributed fabrication and inspection of one atom-based dimensional standard.

2001 With industrial partners, finalize and present specifications for three components of project to appropriate standards committees.

2001 Demonstrate distributed fabrication and inspection of one atom-based dimensional standard using telerobotic operation of an SPM.

Standards & Measurement Services

SRM:

- Si single atom step heights standards, counted atom linewidth standards

Testing:

- Special tests of the SRMs in the to-be-produced

Standards Committees:

- ASME (American Society of Mechanical Engineers) B46 on the Classification and Designation of Surface Qualities.
- ASTM (American Society for Testing and Materials) E42.4 on scanning tunneling microscopy / atomic force microscopy
- Recently, we held a workshop and an informal committee of AFM manufacturers and users was formed. This group has expressed an interest in continuing their association with this project.

Telepresence Microscopy and Microanalysis

Leader: Steel, Eric (CSTL)

Staff: Fahey, Albert (CSTL)
Fowler, Deborah Nickerson
Gormley, Jerry (CSTL)
Jones, Samuel N.
Newbury, Dale (CSTL)
Postek, Michael T.
Small, John (CSTL)
Teague, E. Clayton
Thorne, Barbara (CSTL)
Wheatley, Thomas E.
Zeissler, Cynthia (CSTL)

Total FTE 3.0

1998 MEL Goals, Supported

1. Laboratory research and development.

Project Objective

To develop methods and simulation tools for remote access to and control of advanced microscopes and other instruments used for materials microanalysis, including the creation of standards and standard data for validating these processes.

Needs Addressed

Telepresence microscopy and microanalysis is the remote sharing and/or operation of microscopes/microprobes. The chemical microstructure of material specimens is critical to materials science and technology, semiconductor device development, quality measurements and process control, and failure analysis and evaluation. NIST microanalysis customers need quick access to advanced microscopy and microanalysis instrumentation and expertise, which is especially critical to small start-up firms; they need quality measurements of nanoscale dimensions and material chemistry properties; and they need quick time response for analysis that is demanded by process control. Through demonstrating telepresence in this area, this project is enabling the possibility for the more efficient use of expensive, scarce resources and critical personnel at industrial central laboratories by providing remote, instantaneous, around-the-clock access to critical production facilities; by providing "just-in-time" analysis; and by improving communications within the service analysis industry.

Technical Approach

This project is establishing remote communications with microanalysis customers from NIST labs via inexpensive teleconferencing hardware/software that utilize World Wide Web-based technology, specifically allowing for "over-the-shoulder" remote monitoring of NIST analysis experiments, and specifically targeting small enterprises which account for a large percentage of the industrial community working in these areas. The project is also developing the hardware and software that is necessary for remote control of these types of leading edge instrumentation at NIST labs, specifically utilizing high bandwidth networking technology capabilities. This project is seeking to gain critical research experience in telepresence operation by solving actual problems occurring daily within industry. Ultimately, standards and standard data will be created that validates telepresence microscopy and microanalysis.

Related Developments

- This project has formed a close collaboration with the Materials Microcharacterization Collaboratory project, which is part of the DOE 2000 Initiative, and which has developed electronic notebook software for web-based collaborative experimentation.

Prior Year Accomplishments

- Solved several industrial problems using unique NIST capabilities by collaborating on projects of mutual interest with industry, academia, and government agencies.

- Set up Web sites for remote access to NIST microanalysis analytical and modeling software tools.
- Connected advanced microscopes and microanalyzers into the remotely accessible, collaborative environment.
- Established effective computer communications between and among partner sites through the Internet, which included the evaluation of multiple software/hardware commercial teleconferencing packages.

FY 1998 Plans

- Address several unique issues raised by remote operation, including the ability to respond effectively to the demand for immediate data interpretation, determining and assuring data quality, and the need for real-time measurement and analysis statistics.
- Address communications security issues that are important to collaborators, aiming to establish secure connections without sacrificing communications speed
- Continue developing and testing the speed of the communications connections to facilitate remote control of instrumentation.

Virtual Die Design for Information-Based Metal Forming

Leader: Foecke, Timothy (MSEL)

Staff
Densock, Robert J.
DeWit, Roland (MSEL)
Donmez, M Alkan
Fields, Richard (MSEL)
Fowler, James E.
Gilsinn, David E.
Hicho, George (MSEL)
Keller, Bob (MSEL)
Thomson, Robb (MSEL)
Wilkin, Neil D.

Total FTE 3.0

1998 MEL Goals, Supported

1. Laboratory research and development

Project Objective

To improve the costly and slow trial-and-error methodologies by which the metal forming industry designs dies, ultimately aiming to decrease metal forming industry die tryouts to one.

Needs Addressed

The metal forming industry is a several hundred billion-dollar industry in the United States, with a large portion being accounted for by the automotive industry. New dies for stamped parts for a car model typically cost several hundred million dollars, with costs for an entire car line approaching $2B/year and typical time to production for a new car model of around 50 weeks. The time for producing and trying dies can be on the order of 25-28 weeks. Current die fabrication costs are so high because current die design processes are typically sequential operations involving little concurrent communication among the various technical functions involved in the process.

Technical Approach

The project will incorporate improved materials models into common finite element analysis packages to improve the constitutive laws associated with simulations of forming operations that are used in virtual die design. Anticipated capabilities enabled by virtual die design include more rapid fabrication of sheet metal forming dies and higher precision stamped parts with tighter dimensional tolerances. The project will be concentrating on the development of standard mechanical tests relevant to sheet metal forming, including plane strain tensile tests and channel forming tests; the development of accurate simulations of material responses in forming processes; and on-line techniques for remote data acquisition and control for forming operations.

Prior Year Accomplishments

- Provided initial high-bandwidth communications connectivity to the NIST tensile testing laboratory.
- Completed the preliminary design of the channel forming tests in collaboration with the University of Michigan.
- Completed initial design of the plane strain tensile tests.
- Completed the development of test methods for imaging dislocation substructures.

FY 1998 Plans

- Initiate modeling activities for handling friction.
- Instrument the testing facilities with the appropriate metrology equipment
- Continue development of the standard tests, both plane strain tensile tests and s-channel tests.
- Continue development of improved constitutive laws associated with finite element analysis.

Manufacturing Engineering Laboratory

Precision Engineering

Advancing the State-of-the-Art for Sub-Atomic Scale Displacement Metrology

Leader Howard, Lowell P.

Staff LeBrun, Tom

Total FTE: 1.40

1998 MEL Goals Supported

1. Laboratory research and development:

Project Objective

To advance the capabilities of optical heterodyne interferometry, Fabry-Perot interferometry, and x-ray interferometry such that linear displacement measurements up to 30cm can be performed with uncertainties of 1 pm to 10 pm.

Needs Addressed

Within and external to NIST there are increasing pressures to overcome existing uncertainty limits at the 0.05 nm to 3 nm level in metrology for displacements up to 30 cm. Means to accurately measure these displacements, such as laser interferometers are not commercially available. Within NIST, these uncertainty limitations are a persistent and nagging problem for the molecular measuring machine (M^3) project, the electronic kilogram project and the calibrated AFM project. Externally, NIST is in stiff competition with the recently completed European COXI (Combined Optical and X-ray Interferometer) project that had largely met an objective to measure linear displacements up to 10mm with uncertainties of ~ 10pm and displacements up to 1mm with uncertainties of ~ 100 pm (0.1 nm). By combining our mutual capabilities in the three methods listed, NIST can develop definitive capabilities to achieve uncertainties comparable to these values and over larger displacements. In addition, the microelectronic industry is pressuring NIST capabilities through their needs for ultra-high accuracy displacement control in advanced-lithography mask generators and steppers. This industry is now bordering on the described limits with 3 sigma requirements for critical dimension metrology, being specified by the National Technology Roadmap for Semiconductors, as 1.8nm (four atomic diameters) in 2001.

Technical Approach

We propose overcoming these limits by combining and building competence to advance the capabilities of the three most advanced displacement metrology methods known - optical heterodyne interferometry, Fabry-Perot interferometry, and x-ray interferometry. To make these advances, we need to build competence in new methods for real-time mode matching of laser sources and interferometer cavities, new mechanical systems for ultra-precise, long-travel guideways, and new, non-polarization based heterodyne interferometers. Simultaneous use of multiple approaches in one system would permit, for the first time, a robust assessment of their individual performance limitations and provide a solid means to validate the advancements to heterodyne interferometry, expected to continue as the industry's workhorse.

The research challenge is to properly combine these three metrology methods in a way that exploits each method's strengths, while accounting for each method's drawbacks. The readily accessible 1 pm resolution capabilities of multiple-beam (Fabry-Perot) interferometry must be balanced against its troubles of a range less than 1mm and systematic uncertainties of parts in a million. X-ray interferometry's advantages of having no known systematic errors down to parts in 10EE-08 to 10EE-09 and resolutions of 1 pm must be balanced against its requirements for extremely slow test object speeds of < 1 mm/hr and a demonstrated range of only ~0.5mm. Optical heterodyne interferometry's advantages of operating over ranges up to meters and speeds of 100's of mm/s test object speeds combined with resolutions as good as 1nm with commercial units and optimized in Molecular Measuring Machine (M^3) to resolutions of 0.05 nm must be balanced with its quasi-periodic errors due to polarization mixing and other sources as large as 3 to 5nm with commercial units and 0.25 nm to 1 nm with M^3. Such errors limit heterodyne interferomery's accuracy to 10-100 times the level anticipated from signal-to-noise ratio considerations, indicating much room for improvement.

We propose a three phase approach. Phase I of this program aims at a metrology test stand based on existing technologies which can run intercomparisons among the three interferometric methods discussed above over ranges up to 10 mm. Intercomparisons over this range would enable a careful determination of the polarization mixing and other error sources in two-beam heterodyne interferometry. In addition it would enable a careful study of new interpolation techniques of multiple-beam interferometry and an exploration of the use of adaptive beam forming optics to overcome the part per million errors arising from a mismatching of the mode structure between laser sources and the Fabry-Perot cavity of the interferometer. The test stand would also serve as the first effort ever to achieve over such an extended range servo-control, by several two-beam heterodyne interferometers, of the linear and angular displacements of the moving member of an x-ray interferometer. Continued use of x-ray interferometry as the “gold standard” for optical fringe splitting should then give an improved value for the lattice period of Si in terms of the defacto length standard, an iodine stabilized He-Ne laser, and in-turn national and international frequency standards.

Based on the information gained in Phase I, Phase II will look toward the engineering of new non-polarization based heterodyne interferometers and new phase processing methods that allow fast data processing for both two-beam and multi-beam interferometers. Once validated within the test stand these new methods could be adapted to M3 displacement measuring system.

Phase III anticipates construction and operation of a linear displacement metrology test stand, possibly operating in vacuum, incorporating all the improvements developed in Phases I and II and operating over a range of 30 cm, in anticipation of the use by the semiconductor industry for wafers of this dimension.

Prior Year Accomplishments

- Designed and procured VME computer system.
- Proof of new Michelson interferometer exhibiting 30pm periodic nonlinearity.
- Laboratory conversion.
- Increased staffing.

FY 1998 Plans

- Construct scanning x-ray interferometer with increased count rate.
- Implement six degree of freedom stage characterization and control testbed.
- Demonstrate servo-locked mode matching in Fabry-Perot interferometer.
- Develop testbed for Michelson interferometers to investigate noise limits.

Five Year Plan Goals vs. Fiscal Year

1998 Design System to Correlate 3 Interferometer.

1999 Develop 50 mm Integrated System.

2001 Retrofit or Develop Alternative to Heterodyne Interferometer.

2000 Design 500 mm System.

2001 Develop 500 mm System.

Calibrated Surface Microscopy

Leader: Vorburger, Theodore V.

Staff: Dixson, Ronald G.
Fu, Joseph
Koning, Rainer
Tsai, Vincent

Total FTE: 3.10

1998 MEL Goals Supported

1. Laboratory research and development.
2. Physical-based National and International Systems of Standards and Measurements.

Project Objective

To support high resolution surface microscopes used by U.S. manufacturing industries for micrometer scale metrology.

Needs Addressed

Manufacturers of integrated circuits, optoelectronic devices, data storage media, and optical components use high-resolution surface microscopy for quality and process control. Manufacturers require standards to verify proper instrument calibration and maintain process control. Uncalibrated measurements impact the yield, the process development costs, the scale-up from pilot lines to high throughput manufacturing, and the correlation of product attributes with process models. Calibrated microscopy is an enabling technology for the manufacture of the digitally based consumer products. This market, driven by the convergence of the information and entertainment industries, is projected to grow to three trillion dollars by the year 2002 (John Scully, former CEO Apple Computer (1992)). In 1994, the manufacture of microelectronic devices comprised a world market of $85 billion.

Technical Approach

Atomic force microscopy (AFM) has evolved rapidly since its invention in 1986. AFM has revolutionized surface microscopy, allowing the acquisition of surface topography from both conducting and nonconducting surfaces with unprecedented lateral and vertical resolution. Indeed, AFM has demonstrated a lateral resolution of 0.3 nm and a vertical resolution of 0.01 nm. This microscopy is now being used by NIST for making traceable measurements. The cornerstone of development is an AFM with traceability to the wavelength of light in all three coordinate axes. This "calibrated" AFM (C-AFM) will be used to calibrate pitch and height artifacts for use in U.S. industry. The instrument will calibrate pitch artifacts ranging in size from approximately 10 µm down to 0.2 µm and height artifacts ranging from approximately 1 µm down to 0.3 nm.

Scanning electron microscopy (SEM) is used throughout industry. SEM is used for inspecting products for defects, contamination, and conformance to geometrical tolerances. Also, reliability personnel often rely on SEM to determine the cause of product failure. Accurate, reproducible SEM measurements are dependent upon the availability and use of magnification standards for microscope calibration. Therefore, our mission includes the calibration of Standard Reference Material (SRM) 2070 (evolved from SRM 484), a magnification standard for SEMs. SRM 484 allows SEM operators to calibrate their instruments over magnifications ranging from 1000x to 20000x. Seven previous issues of this popular SRM have been sold. The current issue, SRM 484g, was released in FY96. The project's current metrology SEM is aging. During FY98, we will test the Amray metrology SEM housed in the Nano-Scale Metrology Group for the calibration of SRM 2070.

Prior Year Accomplishments

- Completed measurements of Si single atom step heights using the C-AFM.
- Performed linewidth measurements with the C-AFM as part of the MEL/EEEL linewidth round robin project.
- Published three articles describing the

research results and completed a review article entitled "Industrial Uses of STM and AFM".

- Performed measurements of step heights ranging from 17 nm to 180 nm that were in good agreement with results measured with a calibrated stylus instrument.
- Upgraded the C-AFM with an improved positioning stage.

FY 1998 Plans

- Integrate sample positioning stage in C-AFM.
- Perform first measurements of SRM 2070 with the AMRAY SEM.
- Publish article comparing step height measurements by C-AFM with those obtained with a calibrated stylus instrument.
- Issue first report of test for step height measurement to industrial customer.
- Issue first report of test for pitch measurement to industrial customer.

Five Year Plan Goals vs. Fiscal Year

1999 Publish one or more articles comparing the calibration of step-height standards using the C-AFM, stylus, and interferometric techniques.

1999 Complete linewidth measurements for the MEL/EEEL linewidth project.

1999 Certify SRM 2070, the SEM magnification standard in cooperation with the Nano-Scale Metrology Group.

2002 Operate calibration service of pitch/height artifacts for calibration of AFM microscopes.

2002 Upgrade and maintain the equipment and methods for C-AFM calibration services.

Standards & Measurement Services

SRMs:

- Researching: Pitch/Height specimens for calibrating Scanning Probe Microscopes (SPMs).
- Existing: SRM484/2070 SEM magnification standards, six series of particle size specimens ranging from 30 µm to 0.3 µm in diameter.

Calibrations:

- Calibrated Atomic Force Microscope

Committees:

- BIPM Working Group WDGM7 on Nanometrology.

Collaboration in Dimensional Metrology with Oak Ridge Metrology Center

Leader: Doiron, Theodore D.

Total FTE .10

1998 MEL Goals Supported

2. Physical-based National and International Systems of Standards and Measurements.

Project Objective:

To use the capabilities available at the Oak Ridge Metrology Center (ORMC) to support and enhance PED's ability to deliver world-class precision measurement services to industry.

Needs Addressed

We are meeting the documented needs of American industry for previously unavailable NIST calibration services for long step gages and end standards, two dimensional reference standards, and other basic dimensional measurement services.

Technical Approach

Continue a pilot project for the conduct of certain NIST calibrations at ORMC under the metrological and administrative control of the PED. The Pilot Program was established in 1994 and is continuing. The program has been very successful, measuring a number of U.S. step gages at uncertainties comparable or better than any in the world. The collaboration continues with current work to develop methods to measure the coefficient of thermal expansion of artifacts.

Prior Year Accomplishments

- Calibration of 12 step gages. Test of stability of gages begun by tracking recalibration results for industry gages.
- First measurement made with dilatometer on known artifacts, end standards made of various materials.

FY 1998 Plans

- Begin development of new dilatometer for length artifacts that do not have mirror surfaces like those of end standards.
- Begin calibrations on dilatometer, including thermal time constants and length tracking.

Five Year Plan Goals vs. Fiscal Year

1999 Expand Pilot Program to include ball plate hole plate calibrations

2000 Develop and implement system to measure thermal properties of dimensional gages

2002 Continue Operation of the Pilot Program for step gages and long end standards.

Standards & Measurement Services

Calibrations:

- Step gages, end standards, and dilatometry (coefficient of thermal expansion)

Committees:

- Chair ASME B89.1.9 Gage Blocks

Complex Form Dimensional Metrology

Leader: Harary, Howard H.

Staff: Erber, Edgar G.
Everett, Dennis S.

Total FTE: 1.20

1998 MEL Goals Supported

1. Laboratory research and development.
2. Physical-based National and International Systems of Standards and Measurements.

Project Objective

To develop and extend the world-class dimensional measurement capabilities of MEL to forms with complex shapes (e.g., gears, turbine blades, and propellers) in satisfaction of industry's advanced measurement needs.

Needs Addressed

This project responds to an industry pull for the (re)establishment of NIST as the pinnacle of traceability for complex form 3-D artifacts for gear manufacturers and users (automotive, heavy equipment, aerospace, marine), and other industries. Traceability is a necessity if industry is to maintain the quality and interchangeability of their parts and assemblies, and meet the requirements of ISO 9000 for international trade.

Technical Approach

Building on MEL's existing expertise in the measurement of American Petroleum Institute thread gages we will (1) expand our services to include other complex form artifacts and (2) lower the uncertainty for these measurements. A state-of-the-art high accuracy coordinate measuring machine (CMM), in a suitable temperature and humidity controlled environment, with flexible software will be used to measure the complex forms. Each measurement will be accompanied by a measurement uncertainty to assure traceability to the international standard of length. The uncertainty is at state-of-the art or better (as determined by national laboratories benchmarking). Measurement conditions and procedures will be continually tested and refined in an effort to reduce the uncertainty of the measurement process. We are working closely with our industrial clients through our relationship with American Society Mechanical Engineering's Committee on Gear Metrology (COGM) and the American Gear Manufacturers Association (AGMA) to guarantee that the program addresses industry needs and to ensure customer satisfaction.

Prior Year Accomplishments

- Concluded assistance to M&M Precision Systems, a manufacturer of specialized gear measurement equipment, in bringing to a successful close their ATP-funded project to develop the next generation of gear measuring machine.
- Gear artifact measurement capability has been extended to gear index (tooth spacing) artifacts.
- Worked with gear industry representatives to develop a prototype for an enhanced gear index artifact.
- Currently participating in an international round robin for gear artifacts organized by the British Gear Measurement Center at the University of Newcastle.

FY 1998 Plans

- Extend gear artifact measurement capability to pin artifacts.
- Participate as an active committee member in the writing of American Gear Manufacturers Association/ANSI standard for the calibration of gear measuring machines.
- Investigate the use of closure techniques for reducing the measurement uncertainty of complex artifacts.

Five Year Plan Goals vs. Fiscal Year

2000 Investigate the use of non-contact measurement technologies to increase the speed and density of complex form measurements in cooperation with the Rapid Agile Metrology for Manufacturing (RAM) ATP funded consortium.

2000 Extend the measurement capability to master lead, index and pin artifacts, and master gears.

2001 Enlarge the complex form service measurement service to other complex forms to meet the needs of the aerospace, automotive and marine industries (e.g., turbine blades, airfoils and propeller blades).

Standards & Measurement Services

Committees:

- American Gear Manufacturers Association/ANSI
- American Gear Manufacturers Association's Inspection Handbook and Measurement Machine Calibration Committees
- American Society of Mechanical Engineer's Committee on Gear Metrology

Computational Metrology of Manufactured Parts

Leader: Phillips, Steven D.

Staff: Borchardt, Bruce R.
Estler, W. Tyler
Sawyer, Daniel S.

Total FTE: 1.50

1998 MEL Goals Supported

1. Laboratory research and development
2. Physical-based National and International Systems of Standards and Measurements
3. Information-based National and International Standards and Measurements

Project Objective

Develop calculational techniques to address point coordinate sampling strategies, machine geometry factors, and probe error models, that will allow assignment of traceable uncertainties to measurements performed on coordinate measuring machines (CMMs).

Needs Addressed

In coordinate metrology, including more than 20,000 CMMs in U.S. industry, there is no rigorous methodology to determine if part dimensions conform to design specifications, or to accurately estimate the statistical confidence of measurement results. As a consequence, CMMs could be considered uncalibrated and are not traceable according to the ISO (International Organization for Standards) definition. Since manufacturers have no way to assign realistic uncertainties to CMM measurements, in many cases they are forced to arbitrarily apply overly-conservative and costly ratios between part tolerances and the accuracy required of their measuring machines and NIST-calibrated artifacts. The ISO Guide to the Expression of Uncertainty in Measurement (1995) provides explicit rules for uncertainty computation in terms of error sources and sensitivity coefficients, given a model of the functional relationships between the quantity to be measured and the sources of uncertainty. For a modern computer-controlled CMM, the functional relationships are complex and often unknown. They involve convolutions of the spatial distribution of sampled points, each with its own cloud of uncertainty, with feature extraction algorithms that use various forms of optimization to estimate the locations and geometrys of the features of interest. There is a strong industrial need for a systematic approach toward a generalized solution to this computational problem. Certainly, there is a large competitive advantage for those manufacturers who can demonstrate defensible uncertainties in their CMM measurements of complex work pieces.

Technical Approach

NIST will develop integrated computational models of CMM measurement processes that build upon our significant accomplishments in mapping and software correction of quasistatic machine positioning errors. This work will include quantitative estimates of the size, and effect on measurement process uncertainty, of errors due to (1) point sampling strategies and their interactions with part form errors; (2) CMM machine geometry errors, (3) CMM probe errors; (4) algorithm error in the extraction of part features from coordinate samples; and (5) variable errors due to thermal distortion, machine dynamics, and part-machine interactions. Important elements of this work include the development of faster techniques for machine and probe error mapping and demonstration of a rigorous protocol for estimating the residual uncertainty of CMM measurements after correction for all known systematic errors. We will develop a software simulation program, i.e. a Virtual CMM (VCMM), which can be implemented using industrially accepted CMM performance evaluation methodologies. Uncertainty predictions from this simulation software will be tested using well-calibrated artifacts and test work pieces. Commercialization of this technique will be investigated.

Prior Year Accomplishments

- Granted a Small Business Innovative Research (SBIR) contract to ICAMP Inc. to develop commercial prototype of the VCMM.
- Demonstrated good agreement of uncertainty predictions and CMM measurement errors of well-calibrated artifacts.
- Published archival paper on uncertainty budgets that contain uncorrected bias.
- Published archival paper on estimation of measurement uncertainty of circles using probe error models and first principle calculations of sampling strategy effects.
- Published two archival papers on a detail model and error compensation method for kinematic touch trigger CMM probes.
- Developed a new computational Monte Carlo method to estimate the CMM parametric state based on American Society of Mechanical Engineers (ASME) B89 - Dimensional Metrology Committee B89.4.1 performance data.
- Developed preliminary prototype code demonstrating the use of the new Monte Carlo technique to predict measurement uncertainty.

FY 1998 Plans

- Test ICAMP prototype VCMM software.
- Publish archival paper on the use of Bayesian Inference in uncertainty estimation.
- Experimentally confirm VCMM uncertainty predictions for a wide range of part geometries.
- Investigate methods to simulate thermal error effects in VCMM software.
- Develop multiple feature analysis capability in VCMM software.
- Implement multiple machine geometry types and multiple probe configurations in prototype VCMM software.
- Publish archival paper on the new Monte Carlo calculation technique.

Five Year Plan Goals vs. Fiscal Year

1998 Develop and test initial functional VCMM prototype

1999 Implement thermal models in VCMM

2000 Implement scanning and rotary table VCMM capabilities

2001 Comprehensive VCMM integration with part form error simulation

Standards & Measurement Services

Committees:

- ISO Technical Committee (TC) 213 Working Group (WG) 4 & 10
- American Society of Mechanical Engineers (ASME) WG B89.4.20 - Artifacts Uncertainty, Subcommittee B89.7 - Uncertainty

Coordinate Measuring Machine (CMM) Calibration Methodologies

Leader: Phillips, Steven D.

Staff: Borchardt, Bruce R.
Sawyer, Daniel S.
Snoots, Patricia A.
Ward Jr., David E.

Total FTE: 1.40

1998 MEL Goals Supported

1. Laboratory research and development
2. Physical-based National and International Systems of Standards and Measurements
5. Customer satisfaction and program recognition

Project Objective

To develop methodologies and artifacts for Coordinate Measuring Machine (CMM) calibration, performance evaluation, and task specific measurement uncertainty assessment, in support of the American National Standards Institute (ANSI), ISO - (International Organization for Standards), and U. S. Department of Defense (DOD) metrology standards.

Needs Addressed

U.S. industry, the metrology standards community, and DOD, are currently in a period of rapid transition regarding CMM evaluation and traceability. International competitiveness is forcing compliance with ISO standards. This has created a significant need for the development, characterization, and calibration of high precision artifacts. Additionally, the internationally recognized goal of achieving CMM traceability is driving research on techniques to quantify CMM performance sufficiently well to evaluate task specific measurement uncertainty. Presently, evaluating CMM task specific uncertainty is difficult even in the best laboratories, and complex and expensive to implement in industry. Understanding the CMM hardware interactions at a level sufficient to develop procedures and equipment which can be cost effectively implemented in industry is urgently needed. Similarly, the military is developing an interservice CMM calibration program for use throughout DOD. The goal of this effort is to provide increased quality assurance and establish the traceability of CMM measurements for all DOD sites. A unified approach to CMM evaluation and traceability will reduce duplication of effort in complying with a multitude of standards, which currently are insufficient to establish task specific measurement uncertainty. Such a unified approach will improve the quality of manufactured parts through increased understanding of the measurement process and create a viable means of establishing traceablity for coordinate measuring machines.

Technical Approach

To achieve this goal NIST is working on two broad fronts: (1) creating and coordinating national, international, and DOD standard specifications; and (2) conducting research into CMM performance issues and subsequent artifact development. NIST is actively involved on both ANSI and ISO standard committees. Previously, NIST has shown that the metrological issues of artifact mounting, not the geometrical design, has lead to discrepancies between different performance standards. Using this information, NIST has developed kinematically mounted artifact systems, including the CMM Interim Testing Artifact, to rapidly detect CMM errors. Currently, research is being conducted to leverage this technology into providing detailed information regarding CMM measurement uncertainty. Consequently such efforts could unify national and international CMM standards while gaining additional information regarding CMM measurement capability. NIST is presently leading a DOD effort to create an interservice CMM standard which will embody these concepts, provide industrially viable metrology artifacts, and the methodologies needed to conduct the procedure. Specifically, NIST is investigating ball step gauge designs which are mechanically stable at less than 1 µm/m for lengths up to 1.5 m.

Prior Year Accomplishments

- Published "Guidelines for CMM Interim Testing" in the ANSI B89.4 Standard and completed B89.4 supplement on CMM interim testing for special purpose CMM (independently published by ANSI)
- Delivered four NIST designed CMM interim testing artifacts under contract to the Air Force
- Developed enhanced version of ball step gauge prototype artifact
- Initiated laser ball step gauge artifact design

FY 1998 Plans

- Initiate national and international efforts to unify CMM standards
- Produce first batch of Standard Reference Materials (SRM) calibrated ball bars
- Produce first laser ball step gauge prototype artifact
- Produce multiple stylus test procedure for ISO 10360 standard series
- Initiate an international ball bar round robin

Five Year Plan Goals vs. Fiscal Year

2000 Resolve outstanding standardization issues

2000 Complete DOD CMM standard and procedures and field test at DOD site

2000 Deploy operational test system to industrial test sites for evaluation

2000 Demonstrate performance evaluation and CMM uncertainty assessment capability

Standards & Measurement Services

SRMs:

- SRM 2501 – 2509. These are 300 mm, 400 mm, 500 mm, 600 mm,700 mm, 800 mm, 900 mm, 1200 mm, 1500 mm Fixed Length Calibrated Ball Bars.

Committees:

- ISO Technical Committee (TC) 213 Working Group (WG) 4 & 10
- American Society of Mechanical Engineers (ASME) WG B89.4.7 - Ball Bar Systems, WG B89.4.13 - Interim Testing of CMMs, WG B89.4.20 - Artifacts Uncertainty

Diode Lasers for Length Measurement

Leader: Stone Jr., Jack A

Staff: Howard, Lowell P.

Total FTE: 1.25

1998 MEL Goals Supported

1. Laboratory research and development.
2. Physical-based National and International Systems of Standards and Measurements.

Project Objective

To use emerging diode laser technologies to develop next generation length measurement tools.

Needs Addressed

A variety of customers in the large-scale manufacturing and semiconductor industries will be served by several projects that address length measurement from the tens of meters to the picometer level. Large-scale manufacturers such as the aerospace, automotive and shipbuilding industries need improved ease of use for high-accuracy measurement systems to lower the cost of quality control metrology. Semiconductor manufacturers working towards atomic sized critical dimensions will benefit by having higher accuracy standard reference materials (SRMs) made possible by adding traceable metrology to a variety of NIST calibration tools. Future NIST needs will be supported by building a competence base with diode laser systems for length measurement, which are already beginning to enter the commercial marketplace.

Technical Approach

Improve large-scale manufacturing through the use of absolute interferometry systems based upon tunable diode lasers. Such systems can facilitate measurements of distances up to 50 m with an accuracy limited only by index of refraction uncertainties (10 µm or better at 10 m). An absolute interferometer is tolerant of temporary signal loss, giving flexibility not found in incremental type displacement systems. A first design employing a 670 nm tunable diode laser has achieved uncertainties on the order of 5 µm (2-sigma estimate) on a range of 6 m. The relative uncertainty is thus better than 1e-6 in the lab; in more typical industrial environments this uncertainty will increase due to uncertainty in index of refraction along the measurement path. Later designs will be incorporated into 3-D measurement systems and new index of refraction measuring techniques integrated into our system. Nanoscale measurements are being addressed by teaming frequency tracking Fabry-Perot interferometry with tunable diode lasers and newly available microwave measurement technology. The use of microwave technology permits Fabry-Perot interferometers of a practical size (10 mm to 25 mm) allowing integration into piezoelectric actuators and calibration artifacts. Resolutions are being obtained in the picometer domain with accuracy ultimately expected to reach tens of picometers or better. Ultimately, the system will be integrated into NIST SRM calibration tools for step height measurement and nanoscale
metrology.

Prior Year Accomplishments

- Redesigned Fabry-Perot cavity locking servo electronics.
- Obtained commercially-built 633 nm tunable diode laser for evaluation with Fabry-Perot system of Dynamic Displacement Artifact (DDA).
- Developed test procedures/diagnostics for quantifying sources of uncertainty in absolute distance interferometer (ADI), including relevant spectral characteristics of diode and periodic nonlinearities in fringe interpolation. Submitted paper on periodic nonlinearities for publication.

- Designed stable reference cavity to replace current reference in ADI. This cavity is expected to improve resolution, long-term accuracy, and portability of system.
- Began testing of newly acquired diode laser with longer sweep range, expected to give more accurate ADI results.

FY 1998 Plans

- Complete paper on sources of error in absolute interferometry.
- Design and build miniature cavity, mode-matching and fiber optic beam delivery system for DDA.
- In order to use DDA for AFM calibration, implement temperature-controlled environment and on-line index of refraction compensation.
- Extend DDA frequency-sweep range to 15 GHz.
- In collaboration with NIST/Boulder, explore application of distributed feedback (DFB) laser to ADI.
- Carry out full analysis and characterization of uncertainties in ADI, both for our old ADI system and our new system with stable reference cavity and long-sweep range laser.

Five Year Plan Goals vs. Fiscal Year

1999 Investigate/integrate new technologies as they become available.

1999 Industrial collaborations and dissemination.

1999 Continue collaboration with Boulder on laser source development.

1999 Integrate Fabry-Perot interferometer into SRM calibration tools.

1999 Integrate and test absolute interferometer with 3-D measuring system.

1999 Test, troubleshoot and evaluate uncertainties.

1999 Test hybrid absolute interferometer and compare performance to heterodyne system.

Standards & Measurement Services

Committees:

- B89.18 (lasers), Consultative Committee for Length (of BIPM).

Engineering Metrology Measurement Services

Leader: Stanfield, Eric S.

Staff: Doiron, Theodore D.
Erber, Edgar G.
Everett, Dennis S.
Faust, Bryon S.
Harary, Howard H.
Rannals, Alan T.
Stocker, Michael T.
Stone Jr., Jack A.
Stoup, John R.
Zimmerman, Jay H.

Total FTE: 3.90

1998 MEL Goals Supported

2. Physical-based National and International Systems of Standards and Measurements.
5. Customer satisfaction and program recognition.

Project Objective

To support industry by providing quality calibrations, traceability to national standards, and expert technical advice.

Needs Addressed

This project supports U.S. Industry, other government agencies, foreign industries and laboratories because they need high-accuracy calibration of dimensional artifacts, traceability to a national laboratory, technical guidance, and reasonable calibration turnaround time and price.

Technical Approach:

Perform high-accuracy quality calibrations for private industry, government agencies, laboratories and international companies. This is accomplished by reporting parameter specific data with the lowest attainable uncertainty in a calibration report format that includes a NIST Test Number specific to each calibration (for traceability purposes).

Related Developments

Began enhancing the delivery of our measurement services through the use of the Internet by developing a set of frequently asked questions (FAQs) and a web browser-accessible calculation resource, "Elastic." The "Elastic" resource allows our customers to determine undeformed or deformed dimensions of an artifact by input or selection of: the applied force, geometry specifications, and elastic properties.

Prior Year Accomplishments

- Continued providing technical expertise (in the form of technical assessors) to and proficiency testing measurement and evaluation services for the National Voluntary Laboratory Accreditation Program (NVLAP). Active participation will hopefully ensure that all dimensional proficiency testing is done by NIST that will help maintain the integrity of the accreditation system.
- This program will save industry money by reducing or eliminating the number of repetitive second party calibration supplier audits and provide the US with a hierarchical system of calibration laboratories. In turn, this will reduce the number of low accuracy calibrations performed by NIST and provide more time for measurement research.
- Completed development of and began offering a Displacement Interferometer System Calibration Service.
- Upgraded the mechanical calibration process for long gage blocks from a manual data acquisition process to a semi-automated process by procuring equipment and modifying existing software. This process upgrade will reduce the possibility of data recording errors and will reduce the measurement sequence time; this should ultimately reduce the process uncertainty.

- Completed integration of the laser micrometer into all absolute and comparison measurements performed on cylindrical diameter standards (i.e. cylinders, plug gages, thread wires, and pin gages). Software verification is continuing into the 1998 fiscal year.
- Developed a measurement process for verifying the accuracy of the elastic constants used for correcting measurement results of spherical diameter standards to undeformed conditions. This capability was a bonus obtained through the unique modifications made to the Strang Viewer for use as the gage block phase measurement instrument. Method refinement and uncertainty determination will continue during the 1998 fiscal year.
- Completed development of a gage block phase shift measurement process using the Strang Viewer Interferometer. This method will reduce the uncertainty of phase shift corrections that are applied when performing interfermetric measurements on master gage blocks used in the mechanical gage block calibration services. Method refinement and data collection will continue during the 1998 fiscal year.
- Continued development of new measurement capabilities using the Leitz Coordinate Measuring Machine (CMM) in the gear measurement lab. Using the Leitz CMM we completed lead master measurement intercomparisons with Oak Ridge Metrology Center (Y-12) and expanded our standard ring gage calibration service to include large ring gages (>100 mm diameter). Calibration of large ring gages is done by special arrangement only. Additionally, we received and began evaluation of Leitz developed software for measurement of API Gages.
- Customer calibrations completed in fiscal year 1997 included: (5174) Gage Blocks by Mechanical Comparison, (100) Gage Blocks by Interferometry, (160) Angle Blocks, (14) Optical Flats, (1) Indexing Table, (460) Thread Wires, (140) Spherical Diameter Standards (Balls), (5) Sieves, (23) Ring Gages, (7) Roundness Standards (102) Cylindrical Diameter Standards, (308) Miscellaneous Items. Calibration charges totaled approximately $367K (this excludes calibration program fee and surcharge) in calibrations.

FY 1998 Plans

- Produce and deliver three index of refraction versions of Standard Reference Material (SRM) 2521 Optical Fiber Coating Diameter.
- Continue documenting calibration processes in the form of technical procedures, as well as, improving measurement and customer service processes that are in line with development of a measurement services quality system.
- Complete evaluation of the final version of American Petroleum Institute (API) software. This will enable us to measure all API threaded gages on the Leitz CMM.
- Complete development of a Full Surface Flatness Measurement Service using the ZYGO Phase Stepping Interferometer. This will involve staff training, development of measurement processes, software verification, and evaluation of measurement uncertainty.
- Complete the extensive hardware and software upgrade of the existing Talyrond 3 Roundness Measuring Instrument to include computer; control, data acquisition, and data analysis of cylindricity data. The new software, along with the hardware modifications, will provide us with the ability to use reversal measurement techniques, which are used to separate instrument error and part error. Current electronics are out-dated and cylindricity measurements can only be done with limited accuracy by time-intensive, independent analysis of roundness and straightness data.

- Obtain operational status of the AAMACS (Advanced Automated Master Angle Calibration System) following repair and redesign by the manufacturer and NIST staff. This was previously planned for the 1997 fiscal year, however delays in the repair and redesign have delayed completion of this objective.

Five Year Plan Goals vs. Fiscal Year

1998 Offer Full-Surface Flatness Calibration using ZYGO Interferometer - This instrument will provide full-surface flatness measurement capability, which we do not currently offer. This method will offer a comparable uncertainty to that currently offered for specific diameter flatness and will reduce turnaround time substantially.

1999 Offer a Cylindricity Calibration Service with world class uncertainty - This calibration is being developed in response to numerous requests from many different industries for high accuracy-cylindricity measurement.

1999 Offer calibration of angular artifacts and angular measuring instrumentation using AAMACS -

Use of this instrument will reduce turnaround time, provide lower uncertainty, and will offer a wider range of measurement capabilities.

2001 Complete development and documentation of a measurement services quality system which will be in compliance with current publication of ANSI/NCSL Z540-1 - Benefits to be derived, but not limited to: efficiency, organization (documentation/procedures), and a strong focus on the quality of services provided to our customers.

Standards & Measurement Services

SRMs:

- SRM 2522 - Pin Gage Standard for Optical Fiber Ferrules
- SRM 2523 - Optical Fiber Ferrule Geometry Standard

Calibrations:

- Gage Blocks (10010C), Ring Gages (11040S), Spherical Diameter Standards (11030S), Cylindrical Diameter Standards (11010S), Roundness Standards (13020S), Optical Flats (13010S), Angle Blocks (14010C), Polygons (14020S), API Threaded Plug and Ring Gages (12010C), Thread and Gear Wires (11020C), Sieves (10060S), Step Gages (11060S), Indexing Tables (14030S), Optical Wedges (14040S), Laser Frequency/Wavelength (14510S).

Committees:

- Several members are involved with American National Standards Institute (ANSI) Standards Writing Groups

Engineering Metrology Research and Development

Leader: Stoup, John R.

Staff: Doiron, Theodore D.
Everett, Dennis S.
Faust, Bryon S.
Harary, Howard H.
Stanfield, Eric S.
Zimmerman, Jay H.

Total FTE 2.20

1998 MEL Goals Supported

1. Laboratory research and development:
2. Physical-based National and International Systems of Standards and Measurements:
5. Customer satisfaction and program recognition:

Project Objective

To improve and advance the MEL dimensional measurement capabilities in the areas of length, form, diameter, and flatness.

Needs Addressed

NIST is required to provide traceability to physical and intrinsic national standards that insure standardization for the manufacturing industry of the United States. Steadily decreasing manufacturing tolerances and rapid technological advances in the manufacturing industry are driving the demand for lower dimensional measurement uncertainties and increased coverage and flexibility of NIST capabilities. Improvements in NIST measurement capabilities will have direct economic benefits for our measurement clients by allowing them into areas of design and research previously unapproachable due to measurement constraints. The increased emphasis on global economic standardization and reciprocity requires NIST to maintain levels of dimensional measurement capability equal to those in other national laboratories around the world.

Technical Approach

Using a combination of newly developed measurement techniques, software, and carefully designed hardware upgrades and modifications, we will extend the capabilities of existing MEL dimensional measurement equipment to their practical limits. Serious analysis of the measurement systems and their measurement uncertainty budgets will identify the limitations of the current measurement systems and facilitate efficient strategies for improving the accuracy and lowering the measurement uncertainties for these processes. State-of-the-art statistical process control and environmental compensation and monitoring are NIST strengths in the field of dimensional measurement. Continual improvements in these areas will produce higher accuracy with lower associated uncertainties for these measurements and the ability to minimize the effects of environment on the measurement systems. These improvements will also allow an enhanced analysis of the intrinsic dynamics of the measurement systems and advance our understanding of these effects. In addition to the customer benefits of these activities, we will develop improved measurement services in several ways. We will use unique data collection algorithms and measurement principles to develop new equipment with improved accuracy and range in a fiscally responsible manner. We will procure new equipment when required and implement NIST measurement techniques and statistical process control to extend their intended capability and accuracy. With cooperation from our measurement clients and equipment manufacturers, we will analyze new equipment and measurement processes that are currently available commercially and suggest improvements to enhance their function.

Prior Year Accomplishments

- Developed the optimum positioning and orientation strategy for the Zygo phase stepping interferometer unit and procured the vibration isolation equipment required for the plan.
- Explored the feasibility and began the design of an extensive software and hardware upgrade package for the existing Talyrond 3 roundness and cylindrical geometry instrument.
- Implemented into the gage block measurement process the new technique for measuring and controlling the effects of probe tip wear and penetration corrections for dissimilar materials.
- Produced and delivered SRM 2523 for Optical Fiber Ferrule Diameter.
- Implemented a green laser in the long gage block interferometry system.
- Completed the measurement software required for implementing the comparison version of the laser micrometer for all wire and cylinder measurements.
- Developed an extensive re-engineering strategy in cooperation with the manufacturer, AG Davis, for the Advanced Automated Master Calibration System (AAMACS) angle positioning instrument.
- Performed interferometric phase change on reflection measurements on gage blocks of four materials from six manufacturers.

FY 1998 Plans

- Conduct initial research on a new gage block measurement system that eliminates the wringing film from the measurements.
- Conduct initial research for a new generation ring gage measurement system with measurement uncertainties less than 25 nm.
- Develop initial hardware designs for dilatometry capability using the Zygo interferometer.
- Complete the setup of the Zygo interferometer workstation and determine the current performance level using available check standards and process control techniques for full form flatness measurements.
- Conduct testing and determine the initial performance level of the re-engineered AAMACS angle positioning instrument.
- Develop an improved strategy for cylindrical form measurement using the newly upgraded Talyrond 3 instrument.
- Develop an improved and more inclusive roundness measurement process using the hardware and software upgraded Talyrond 3 instrument.
- Produce more phase change measurements on gage blocks and platens to address the wringing film thickness variation issue.
- Complete the artifact positioning system and fully integrate the comparison laser micrometer into the diameter measurement service with all measurement assurance and process control requirements.

Five Year Plan Goals vs. Fiscal Year

1999 Develop an autocollimator measurement capability using the AAMACS.

1999 Develop the Zygo interferometer into a world class full form flatness measuring instrument with lower measurement uncertainties than current capability

1999 Develop a new cylindricity measurement process using the Talyrond 3

2000 Generate world class and flexible angular measurements using the AAMACS system. Artifacts include polygons, angle blocks, indexing tables

2000 Generate dilatometry capability using the Zygo interferometer workstation

2000 Develop a new generation ring gage measurement system with a large range capability and measurement uncertainties less than 25 nm

2001 Develop a new gage block absolute measurement system that eliminates the wringing film from the measurements with measurement uncertainties of 10-15 nm

Standards & Measurement Services

SRMs:

- SRM 2521 - Optical Fiber Coating Diameter
- SRM 2523 - Optical Fiber Ferrule Diameter
- SRM 2522 - Pin Gage Standard for Optical Fiber Ferrules

Testing:

- 10050S Special Test of Length Standards
- 11050S Special Test of Length and Diameter

Committees:

- B89.2.3 Specification and Calibration of Optical Polygons
- B89.1.5 Measurement of Plain External Diameters for Use as Master Discs or Cylindrical Plug Gages, B89.1.6 Measurement of Qualified Plain Internal Diameters for Use as Master Rings and Ring Gages

Fabrication and Metrology for Nanoelectronics

Leader: Dagata, John A.

Total FTE: 1.00

1998 MEL Goals Supported

1. Laboratory research and development
2. Physical-based National and International Systems of Standards and Measurements

Project Objective

Develop a comprehensive understanding of advanced manufacturing on the nanometer scale by working closely with members of Electronics and Electrical Engineering Laboratory (EEEL) and others on the fabrication and measurement of ultra-precise electronic devices, primarily through the integration of scanned probe microscopy (SPM)-based techniques and SPM instrument development.

Needs Addressed

Materials-related issues become a significant problem below 100 nm in the metrology and process control of important US industries, such as in the production of semiconductor chips, data storage devices, and in research and development (R&D) for polymers & coatings. Strategies which exploit the multifunctional capabilities which are uniquely possible with SPM will draw industry interest and support for these next-generation technologies. It is important that MEL demonstrate leadership regarding the new challenges of nanometer-scale manufacturing metrology and depth of experience in employing SPM-based solutions.

Technical Approach

Integrated fabrication and characterization of nanoelectronic device materials and structures is being carried out using the technique of SPM oxidation, originally developed within PED in 1990. An appropriate electrical characterization technique, scanning Maxwell-stress microscopy (SMM) has been identified and integrated with the oxidation circuitry. The ability to perform electrical measurements of the critically dimensioned device structure during fabrication, prior to completion and full testing of the entire device, is a key quality-control element of this approach.

Related Developments

- Tuning-fork technology development (see below)

Prior Year Accomplishments

- Industrial Applications of Scanned Probe Microscopy - Planned and carried out 4th IASPM workshop at NIST on May 6-8 1997. Attendance was 120 people, about 50 from industry. There were about 30 oral and 20 poster presentations in the areas of semiconductor, data storage, polymers & coatings, and standards development.
- Tuning Fork Technology Cooperative Research and Development Agreement (CRADA) with TopoMetrix.
- Established CRADA # CN-1449, enabling PED to evaluate a promising novel SPM sensor design with particular advantages for industrial applications and fundamental metrology.
- Designed and contracted the production of a low-cost, manufacturable, microfabricated SPM tip assembly, in collaboration with John Suehle of EEEL, which will be used in the evaluation of tuning fork performance.
- Collaborative Research Visits to Electrotechnical Laboratory Tsukuba Japan - December 1996 - January 1997 (6 weeks); May - June 1997 (3 weeks);October - November 1997 (3 weeks);March 1998 (planned)

- These research visits, partially supported by the Japanese government agency MITI, have enabled PED to rapidly evaluate and gain experience with the SMM technique and to begin design and planning of an in-house system based on modification of the TopoMetrix system recently acquired by MEL as part of the NAMT.
- Publications resulting from these visits include: "Evaluation of Scanning Maxwell-stress Microscopy for SPM-based Nanoelectronics", J. A. Dagata, Nanotechnology 8 A3 (1997); "Integrated SPM Fabrication and Characterization: Understanding the Silicon Oxidation Mechanism", J. A. Dagata, T. Inoue, J. Itoh, and H. Yokoyama, Appl. Phys. Lett., submitted; and "Visualizing Sub-phase Distributions in Ultrathin Polymer Blend Films", J. A. Dagata, A. Karim, J. F. Douglas, J. G. Gillen, J. Fu, T. Inoue, J. Itoh, and H. Yokoyama, Science, in preparation.
- Invited talks include: SP-NANO '96, Tsukuba Japan, December 19-20 1996; STM'97, Hamburg Germany, July 17-21 1997; QFD '97, Gaithersburg MD, November 5-7 1997; and Surface Characterization of Adsorption and Interfacial Reactions II, Engineering Foundation Conference, Kona HI, January 11-16 1998.

FY 1998 Plans

- Procure remaining instrumentation required for in-house tuning-fork based SMM capability. Demonstrate the performanceof this system.
- Evaluate tuning fork.
- Complete manufacturing process development of tuning-fork sensor with microfabricated tip.
- Research visit to Electrotechnical Laboratory, tentatively scheduled for March 1998, to continue integrated nanoelectronic fabrication and characterization. Specific device concepts are now being evaluated which can make use of our recently obtained silicon oxidation results.

Five Year Plan Goals vs. Fiscal Year

1999 Establish superior performance of an in-house tuning-fork-based fabrication/characterization system.

2001 Design and fabricate novel functional nanoelectronic device structures.

Standards & Measurement Services

Committees:

Organized IASPM with SEMATECH, American Society of Testing and Materials (ASTM), and American Vacuum Society. This conference focused attention on the need for standards in this area and industrial development of these techniques.

Hexapod Metrology

Leader: Rudder Jr., Fred F.

Staff: Sawyer, Daniel S.

Total FTE: 1.50

1998 MEL Goals Supported

1. Laboratory research and development
2. Physical-based National and International Systems of Standards and Measurements

Project Objective

Develop metrology system to characterize the positioning accuracy of the Advanced Machine Tool Structure Testbed Ingersoll Octahedral Hexapod machining center and a metrology system to provide enhanced positioning accuracy of the machining center. The characterization system will apply to the class of machining centers based upon the Stewart platform concept. The metrology system for enhanced positioning accuracy is specific to the Ingersoll configuration of the Stewart platform concept. The metrology database and systems will be enhanced to support external user interface within the National Advanced Manufacturing Testbed (NAMT) environment.

Needs Addressed

Machining centers based upon the Stewart platform concept promise to introduce a degree of precision machining productivity and production economy not possible with conventional machine tool structural configurations. The combination of structural rigidity, high-speed tool positioning, and full six-axis motion control are features that have drawn the attention of the automotive and aerospace industries and the tool, die, and mold manufacturers. Since the machine configuration is not based upon fixed-axis mechanics, but upon computationally intensive, servo-control algorithms, the need to perform tool position metrology for this class of machine tools is critical both to characterize the positioning accuracy of the tool tip and evaluate the performance guarantees of such systems. Further, since the motion control is based upon feedback of linear displacement measurements and models of the Stewart platform kinematics, the real-time metrology of this new class of machine tools is essential to realizing the performance potential. Precision material removal is an essential function of U.S. manufacturing industries and the potential for increasing productivity that is offered by Stewart platform machine tools will likely be an important element in maintaining U.S. manufacturing competitiveness.

Technical Approach

The project has three distinct objectives: develop metrology tools for directly characterizing tool tip positioning accuracy for the generic class of machine tools, implement on-machine metrology to enhance the positioning accuracy of the Ingersoll Hexapod system of the NIST Advanced Machine Tool Structure Testbed, and provide access to the metrology data base via the NAMT environment. To achieve the first objective, we are implementing a metrology system to characterize, simultaneously, the six degree-of-freedom motion of the tool tip as the machine tool performs a straight line vector move across its work volume. Because this metrology system is not machine-specific, it can be used for any particular implementation of the Stewart platform concept. The system uses a reference straight-edge, six linearly variable displacement transducers for straightness and angular motion, and a laser interferometer for linear displacement measurement. The second objective is long-erm and considers the specific configuration of the NIST Hexapod system. The current concept is to use a laser-based displacement measuring system to provide strut extension data. Specific details of the configuration are now being implemented on the NIST Hexapod Strut Test Stand. Characterization of the tool tip positioning accuracy and the thermal state of the NIST Hexapod is the first step in defining the machining potential of the NIST Hexapod system. The characterization of the octahedral structural frame is necessary to establish the stability of the machine's metrology frame. This characterization task requires the development and use of large-scale metrology techniques that are distinctly different than the tool-tip characterization. Current plans are to use an absolute distance measuring laser tracker to perform the characterization.

Related Developments

- Within the past two years (FY96 and FY97) nine different configurations of hexapod-type machine tools have been introduced into the market place. Further, the German machine tool industry in collaboration with their technical universities are proceeding on an intensive design/development program to investigate parallel structure configurations for conventional three axis machining applications. All of these competing machine tool configurations represent challenging metrology issues so that their accuracy claims can be consistently evaluated. The NIST Hexapod Metrology Project focuses directly on these issues in support of the competitive posture of the US machine tool industry.

Prior Year Accomplishments

- Expanded dynamic analysis of articulated platform to include modal analysis calculations.
- Completed analysis of thermal expansion of heated ball screws (NISTIR 5975).
- Procured instrumentation and calibrated IR thermocouples.
- Performed modal analysis experiments on Hexapod platform.
- Continued metrology characterization using laser system.
- Initiated data acquisition software for metrology system.
- Installed and initiated calibration of metrology system.

FY 1998 Plans

- Conduct thermal expansion measurements of Hexapod test strut using laser IR thermocouple systems.
- Refine concepts for implementation of on-machine motion control metrology system for NIST Hexapod.
- Continue metrology characterization using laser system.
- Develop designed experiments for machine metrology system.
- Design, fabricate and install support fixture for metrology system reference beam.
- Complete data acquisition software and calibration of metrology system on coordinate measuring machine (CMM).

Five Year Plan Goals vs. Fiscal Year

1998 Report details of metrology system and procedures developed to ASME Standards Committee B5: Machine Tools-Components, Elements, Performance and Equipment.

1998 Analyze metrology data and report results.

1998 Assemble hardware, develop data acquisition software, and calibrate metrology system.

2001 Implement on-machine metrology system for NIST Hexapod.

2001 Refine and demonstrate on-machine metrology system for NIST Hexapod.

Standards & Measurement Services

Committees:

- American Society of Mechanical Engineers (ASME) WG B89.4.17 - Vibration Analysis of CMM sites

High Accuracy CMM Development

Leader: Doiron, Theodore D.

Staff: Everett, Dennis S.
Harary, Howard H
Stocker, Michael T.
Stone Jr., Jack A.

Total FTE: 1.55

1998 MEL Goals Supported

1. Laboratory research and development
2. Physical-based National and International Systems of Standards and Measurements

Project Objective

Support industry two dimensional measurements through calibration of grid plates, development of calibration algorithms, a standardized uncertainty budget, and by organizing interlaboratory comparisons.

Needs Addressed

One-and two-dimensional artifacts are the primary means that industry uses to provide traceability for dimensional measurements. These artifacts are used to calibrate or verify the metrology of most measuring machines and particularly for coordinate measuring machines (CMMs). Industry needs break down into two different size regimes. The large scale measurement systems make measurements at the 2 µm uncertainty level on artifacts up to 1 m^2. The artifacts include PC boards, arrays of components, and flat panel displays. These systems will be supported by calibrations of grid plates on the Moore M-48 measuring machine.

The small scale measuring systems are used by the semiconductor mask industry. These systems have ranges up to 200 mm^2, and have repeatability in the 10 nm to 100 nm range. Since NIST does not have an instrument with these capabilities, we are working toward standardizing measurement procedures and the development of an industry interlaboratory comparison system which would provide interim standards.

Technical Approach

For the large scale measuring machines the NIST M48 CMM will provide calibration uncertainties in the 0.3 µm to 0.5 µm range. This system has been retrofit with a commercial control system which will make the machine more reliable and flexible.

We have built a small range measuring machine, M4, as a test bed for measurement algorithms, and as a test instrument to work on deriving error budgets. Along with two private industry researchers, we are developing measurement algorithms that use our best measurement, one dimensional line-scales, along with multiple measurements in different orientations on the new 2D machine, to provide a calibration of both the grid plate and the measuring machine. These algorithms are being tested with data from our measuring machine.

Prior Year Accomplishments

- M4 is running. We have taken considerable data on the machine performance and have made measurements to test new calibration algorithms.
- The Moore M48 CMM retrofit has been successfully completed and the error map is being developed. The machine is now in service for most calibrations using the touch probe. The video probe is not net been integrated into the system, so grid plates are not currently being calibrated.

FY 1998 Plans

- We are also working to perfect robust algorithms for finding the grid mark on plates. Since the commercial systems all have different sensors, we will explore systematic effects of different sensors of the grid measurements. With our video-based system, we will be able to emulate most of the currently used sensor systems.

- M4, our smaller machine, will continue to be used for algorithm tests.
- Finish M4 accuracy studies. These performance tests will be used to develop the next generation effort for small grid plates.
- We shall also begin interlaboratory tests with other high accuracy CMMs in government and industry labs.
- M48 will return to service for grid plate calibrations, and we expect to begin accepting other artifacts, such as step gages and ball plates for calibration.

Five Year Plan Goals vs. Fiscal Year

1999 Interlaboratory comparisons of 2D calibration systems

2000 Characterize small experimental 2D machine

2000 Implement 2D calibrations for Grid Plates on the M48

2002 Build new experimental 2D measuring machine

Standards & Measurement Services

Calibrations:

- Dimensional gages of 1, 2 or 3 dimensions, such as ball plates and step gages

Committees:

- Member of ASME B89.4.18 on video probes and optical comparators

Laboratory Development

Leader: Scace, Brian R.

Total FTE: 1.00

1998 MEL Goals Supported

1. Laboratory research and development

Project Objective

The objective of the project is to provide Precision Engineering Division (PED) and Manufacturing Engineering Laboratory (MEL) personnel with solutions to physical environmental issues affecting reported research results.

Needs Addressed

The immediate target customers for project outputs are PED and MEL researchers. The customers' technical needs vary with specific problems addressed. An entire research facility, such as the PED Moore M48 facility, may be provided from concept through design, construction, and acceptance testing. In other cases, a specific problem area such as retrofit of improved temperature controls or vibration isolation and damping may be addressed. The project also provides for coordination and supervision of both in-house assets (Plant Division) and outside architectural and engineering firms and contractors to complete construction or modifications to the researcher's satisfaction. The customer-project personnel are free to pursue other project goals in parallel with facility construction/modification. This results in savings in time while providing a laboratory environment within which best results may be attained.

It should be understood that, as manufacturing metrology continues to be developed and refined, the environment within which this is performed must also evolve. While the majority of the project's effort is directed internally (within MEL), its effect is felt indirectly with reported results from customer- projects to industry.

Technical Approach

As new levels of accuracy in manufacturing metrology are required, it is becoming increasingly apparent that the current PED/MEL research facilities are obsolete. The project's approach to this issue is manifested in two forms.

First, the project works with PED/MEL researchers to upgrade individual facilities within the current General Purpose Laboratories (GPLs). An example of this approach is the removal of a technically flawed vibration isolation system in Rooms B26/28 in Building 220 and replacing it with a solid floor system of appropriate mass to eliminate amplification of incoming ground vibrations induced by vehicular traffic, footfall, and building mechanical systems. The resulting usable space was then renovated to accommodate the Surface Roughness Standard Reference Material (SRM) Calibration effort. Although originally PED-specific, this project can expand to become MEL-wide.

Second, the project serves as MEL's input to the Capital Improvement of Facilities Project (CIFP). The CIFP, part of the Office of Administration, is responsible for the construction of the Advanced Measurement Laboratory (AML) and for complete renovation of selected GPLs. In this capacity, the project directly communicates with MEL researchers, recognized outside experts in the field of advanced facility design, contracted Architectural and Engineering Firms (A&E), contractors, and the CIFP office to insure that MEL researcher's technical needs are addressed.

Prior Year Accomplishments

- Consulted in the design & construction of the Mass Facility in Bldg. 225 for the Automated Production Technology Division.
- Completed MEL participation in the economic analysis of the CIFP Program with

Booz-Allen & Hamilton, Inc. resulting in the Capital Assets Economic Analysis published June 20, 1997.

- Completed MEL participation in the CIFP Program Re-Assessment Study with SH&G, Inc. resulting in the Program Re-Assessment Preliminary Report published in April 1997.
- Completed air filtration project for those PED activities supporting the Micro-electronics industry. The programs involved were the Line-Scale Interferometer, Calibrated Surface Metrology, Line-Width Calibration, Surface-Nanometrology, Optical Surface, and Optical Metrology.
- Completed construction of PED SEM & Probe Metrology Research Facilities in Bldg. 220. These labs house two Scanning Electron Microscopes requiring particulate mitigation, clean power, de-ionized water, and a nitrogen supply system.

FY 1998 Plans

- Continue design and construction phases of AML as MEL technical representative to the CIFP.
- Begin construction of Xcalibir research facility in Bldg. 225.
- Continue general upgrades of occupied technical space.

Five Year Plan Goals vs. Fiscal Year

2002 Design and construct retrofit of individual GPL technical spaces per PED program requirements and develop this activity's base across the whole of MEL.

2002 Represent MEL regarding technical quality of AML.

2002 Coordinate fit-out of AML space and preliminary migration plan for those elements of MEL displacing to the AML.

Large Scale Coordinate Metrology

Leader: Fronczek Jr., Charles

Staff: Caskey, Gregory W.
Estler, W. Tyler
Hartsock, Ronald G.
Sawyer, Daniel S.
Snoots, Patricia A.
Ward Jr., David E.

Total FTE: 2.80

1998 MEL Goals Supported

1. Laboratory research and development
2. Physical-based National and International Systems of Standards and Measurements
5. Customer satisfaction and program recognition

Project Objective

To (1) develop American National Standards Institute (ANSI) and International Organization for Standards (ISO) standardized tests for large scale three-dimensional coordinate metrology instrumentation, (2) provide high accuracy dimensional calibration of large scale artifacts, and (3) assist U.S. industry in the use of large-scale coordinate metrology.

Needs Addressed

Large-part manufacturing is requiring ever decreasing tolerances. Many large-scale parts, even in high technology applications, lack interchangeability due to dimensional variation. For example, a large commercial aircraft may require more than one ton of shims in order to complete its assembly. This increase in weight can result in additional operation costs of nearly $1M per year per plane. Furthermore, replacement parts must be custom-made since proper dimensional alignment cannot be achieved. These dimensional metrology problems result in increased component costs, operating costs, down time in maintenance due to custom fitting, and pollution.

Large-scale coordinate metrology is an area which can make a substantial contribution to reducing these problems associated with the inability to meet part tolerances during both the part manufacture and assembly processes. However, this is a relatively neglected field of metrology which lacks, among other things, specific national or international standards for metrology instrumentation. Consequently, it is not uncommon to discover that different measurement systems, e.g., laser trackers, theodolites, and articulating arm CMMs, may repeatedly give significantly different results. Similarly, the domestic infrastructure for high accuracy calibration of large dimensional standards is nearly nonexistent and manufacturers often must rely on foreign sources for calibration services

Technical Approach

Large-scale coordinate metrology problems are addressed on several fronts in this project. National and international standard committees are being established to specify the metrology characteristics of measurement instrumentation. NIST participation on these standard bodies is essential to insuring that domestic manufacturing needs are addressed. Simultaneously, NIST will conduct research into theodolites and laser tracker systems to determine and quantify the error sources and seek methods for error elimination. This research will be coordinated with U.S. industry to target difficult manufacturing problems. In addition, the development of the Large Scale Metrology Calibration and Research Laboratory will provide a facility to perform high accuracy calibrations and measurements. For example, the interferometric based long length measuring machine, once completed, will provide measurement capability at an accuracy target level of 0.25µm ± 0.4µm/m for measurements up to 3m.

Prior Year Accomplishments

- Consulted with the Department of Defense (DOD) on large-scale measurement problems including measurements on a dynamic mass, photogrammetric target calibration, and submarine launch tube geometry measurements.
- Developed final mechanical portion of ball bar measurement system.
- Developed software for ball bar measurement system, accommodating laser and environmental sensor inputs.
- Began development of geodetic level rod automated measurement system.
- Provided leadership and support roles in the development of an American Society of Mechanical Engineers (ASME)/ American National Standards Institute (ANSI) Laser Tracker Standard.
- Worked with U.S. manufacturer of laser trackers to gain access to European markets by acting as a liaison between European measurement accreditation agencies.

FY 1998 Plans

- Work with US industry to continually assess and meet their standardization, artifact and measurement method development, and calibration needs in the area of large-scale coordinate metrology.
- Provide support for NAMT Hexapod project by conducting critical large-scale measurements.
- Continue to participate in the development of standard for laser trackers, including evaluation of drafts for validity and practicality and introduction of a completed draft standard to the international community for consideration as an ISO standard.
- Participate in a planned National Measurement Institute (NMI) Key Comparison of ball bar calibration capability.
- Begin calibrating ball bars for use in assessing large-scale coordinate metrology instruments.
- Initiate development, with an industrial partner, of a virtual laser tracker model and software for assessing uncertainty in measurements made with this technology.

Five Year Plan Goals vs. Fiscal Year

2000 Improve the long length interferometric measuring machine to ± 0.25µm + 0.4µm/m.

2001 Develop large scale artifact for intercomparison of several different measurement instruments technologies.

2001 Coordinate ASME/ANSI laser tracker standard.

2001 Coordinate ANSI and ISO theodolite standards.

2001 Conduct large-scale artifact round robins with other national laboratories.

Standards & Measurement Services

SRMs:

- SRM 2501 – 2509. These are 300 mm, 400 mm, 500 mm, 600 mm,700 mm, 800 mm, 900 mm, 1200 mm, 1500 mm Fixed Length Calibrated Ball Bars.

Committees:

- ISO Technical Committee (TC) 172 Subcommittee 6; American Society of Mechanical Engineers (ASME) WG 4.7 - Ball bar systems, WG 4.14 - Non-contact Scanning Probes,WG B89.4.19 - Optical Coordinate Measuring Systems, WG B89.1.7 Surveying Tapes, WG 4.22 - Portable CMMs.

Light Scattering From Features and Surfaces

Leader: Marx, Egon

Staff: Song, Junfeng
Vorburger, Theodore V.

Total FTE: 1.20

1998 MEL Goals Supported

1. Laboratory research and development

Project Objective

To complement work done within the Precision Engineering Division and elsewhere at NIST with calculations of electromagnetic wave scattering by different media and to apply these methods to model surface coatings in manufactured products and to verify layer alignment in the semiconductor industry.

Needs Addressed

The theoretical component of this effort interacts with established and new projects at NIST, such as the competence project on reflectance of materials that deal with scattering of light and other electromagnetic waves. The automotive, aerospace, architectural, and other industries would like to model the reflectance properties of their products as well as the future appearance of weathered products, in terms of design parameters without having to manufacture and test actual samples. Image rendering, which brings the product in its design stage to the computer screen, uses the illumination properties of the light source and the reflectance properties of the surfaces. The semiconductor industry is faced with the critical problem of the alignment of semiconductor layers in the manufacture of their devices as the size of the features becomes ever smaller. Light scattering is a desirable inspection method usable during manufacture. The measurement of the surface roughness is becoming increasingly important in industry, because more stringent surface specifications are required as products tend to miniaturize and become more precise in functioning. The optical techniques are recently finding many applications in the measurement of surface finish as non-contact, non-destructive methods. As a rapid and area averaging method, light scattering is most promising for on-line measurement, which is essential for tight quality control. These are fundamental measurement issues that are part of the NIST mission.

Technical Approach

We use integral equations derived from Maxwell's equations to compute the scattering of electromagnetic waves by different objects. These equations are exact and incorporate the radiation condition, and rigorous methods such as this one are required in the resonance scattering regime where the dimensions of the scatterer are comparable to the wavelength of light. Integral equations also facilitate the concentration of sampling points in regions of interest. A full three-dimensional problem involves a large number of unknowns, and the size of solvable problems is limited by the memory available even on mainframe computers. The single integral equation method is used to reduce the memory requirements. Each geometrical configuration requires a specialized set of variables and equations that take into account the characteristics of the scatterer. Approximate methods may be developed for light scattering by objects with features that are either large or small compared to the wavelength of light. Rough surfaces can be characterized by the power spectral density (PSD). The properties of light scattered by surfaces can be represented by the bidirectional reflectance distribution function (BRDF). The study of scattering of electromagnetic waves by dielectric wedges, a geometry that represents edges on real objects and the exterior region for a particle on a surface. This work supports the development of codes used to compute the distribution of light scattered by complex systems.

Experimental Component: For the reflectance of materials project, we will measure coated surfaces with a confocal scanning optical microscope, an interferometric microscope, and a stylus instrument and compare the results. These data will be used to calculate the BRDF for light scattering from the surface, which will be compared with measurements of BRDF made in the Physics Laboratory.

Related Developments

We are exploring the establishment of a joint project with the Physics Laboratory on the relationship between roughness and emissivity with application to temperature measurement in rapid thermal processing of silicon.

Prior Year Accomplishments

- Derived integral equations for light scattering by a dielectric or perfectly conducting target in a silica layer with and without a covering resist layer. Derived the modified equations for a target resting on the substrate. Derived integral equations for light scattering by particles in a coating on a substrate and for particles partially exposed on the (possibly rough) surface of the coating in different combinations.
- Derived integral equations for light scattering by a set of parallel dielectric strips on a dielectric substrate for transverse electric and transverse magnetic modes, and for arbitrary polarization and direction of incidence.
- Performed PSD analysis of round robin profile measurements of Si wafter surfaces, as well as of additional profile measurements of these surfaces done at NIST.
- Continued work on the theory and measurements of light scattering distributions from sinusoidal rough surfaces in collaboration with the Physics Laboratory and the Korean Research Institute of Standards and Science.
- Assisted in the purchase of a confocal scanning optical microscope.

FY 1998 Plans

- Use the confocal scanning optical microscope on coated surfaces and compare the results with measurements using an interferometric microscope.
- Develop a code to compute light scattering by a spherical dielectric particle on a dielectric plane surface.
- Complete publications on the PSD of one-dimensionally and two-dimensionally rough plane and sinusoidal surfaces in cooperation with the industrial participants in the round robin and the Korean Research Institute of Standards and Science.
- Develop a code to compute the distribution of light scattered by a set of parallel dielectric strips on a plane substrate. Extend to strips of different materials.
- Compute the BRDF of a dielectric coating with varying roughness and compare with measured BRDF data.

Five Year Plan Goals vs. Fiscal Year

1998 Perform measurements of coating morphology for clear coatings, pigmented coatings, and coatings with metallic particles.

1999 Develop theoretical criteria for detectability of small particles on rough surfaces.

2001 Facilitate the inspection of overlay in the manufacturing of semiconductor devices by determining the light scattered by targets in dielectric layers.

2002 Model the light scattering properties of coatings on metallic and dielectric surfaces by computing the BRDF for new and weathered products by taking into account surface roughness, pigments, and metallic particles in the coatings.

Standards & Measurement Services

Committees:

American Society for testing and Materials (ASTM) Committee E-12 on Appearance and the Council on Optical Radiation Measurements (CORM).

Linewidth Correlation

Leader: Villarrubia, John S.

Staff: Dixson, Ronald G.
Jones, Samuel N.
Postek, Michael T.
Potzick, James E.

Total FTE 1.60

1998 MEL Goals Supported

1. Laboratory research and development
2. Physical-based National and International Systems of Standards and Measurements

Project Objective

To improve linewidth measurement capabilities within PED and other related NIST groups through comparative experiments among practitioners of different measurement techniques.

Needs Addressed

NIST is responsible for providing linewidth standard reference materials (SRMs) and/or calibration services to meet the needs of U.S. industry. Presently, our only linewidth standards are optical photomask standards, the minimum linewidth of which is 0.5 µm with a total uncertainty (using the new rules for uncertainty calculation) of ~50 nm 2 sigma. To support present and future semiconductor technologies, industry needs to measure submicrometer lines with uncertainties, as identified by Semiconductor Manufacturing Technology (SEMATECH), of 20 nm or better. The magnetic recording and photographic industries have gap width and grain size measurement requirements at approximately the same scale. Neither NIST nor other national laboratories presently offer a linewidth measurement service or a SRM with this level of accuracy.

Physical linewidth determination with any microscopic technique requires modeling of the probe/sample interaction in order to identify edge locations. One barrier to accurate linewidth determination has been acquisition of models in which we can have the required level of confidence. A second barrier is lack of consensus on the definition of linewidth.

Technical Approach

Linewidth measurement capabilities at NIST span several techniques, including optical, scanning electron, and scanned probe microcopies for physical linewidth, as well as electrical techniques to measure the average width of conducting paths. This project seeks cooperative interactions among practitioners of the various techniques. This cooperation will include information exchange among practitioners of the various methods. It will also include design and eventual execution of experiments for cross-technique comparison of measurements.

We will cooperatively design experiments to measure the same linewidth artifacts by two or more techniques. Experimental design will include all factors relevant to good measurement practice, including sample handling, definition of linewidth for purposes of this experiment, and a manufacturable linewidth artifact or artifacts measurable by multiple techniques. If possible, we will design a single artifact measurable by all of the methods. If this proves impractical, we might design several artifacts optimized for pair-wise comparisons linking all of the methods. We will seek industry cooperation in the fabrication of these artifacts. In parallel with efforts to design artifacts with desirable features, we will seek opportunities to begin measurements with specimens either in hand or easily accessible, despite their less desirable properties.

The goal of measurements on these artifacts will be to document any existing discrepancies between methods. In the unlikely event that no such discrepancies are found, confidence in all of the techniques (including the probe/sample interaction models) would be significantly enhanced. In the more likely event of discrepancies, identification of the sources and remediation will enhance NIST's overall linewidth capabilities.

Prior Year Accomplishments

- Blind reconstruction (BR) method for tip shape determination (developed for the projects SPM modeling effort) was made publicly available via publication [J. Res. Natl. Inst. Stand. Technol. 102, 425 (1997)] and indexed on the world wide web. A version of BR was adopted by Digital Instruments for their Dimension 9000 instrument.
- Agreed upon a measurement plan for electrical, scanning electron microscope (SEM), and atomic force microscope (AFM) measurements of linewidth specimens.

FY 1998 Plans

- Scanned probe, SEM, and electrical linewidth teams each to complete a linewidth measurement on our NIST/Sandia artifact, this measurement to include: (a) correction for the probe/s ample interaction, using the current best-practice method for each technique (imaging methods only) and (b) an error budget (all methods).

Five Year Plan Goals vs. Fiscal Year

1998 Perform linewidth measurements on specimens using electrical, SEM, and AFM.

1999 Develop revised edge location models and/or linewidth working definition to reconcile differences uncovered in measurements.

1999 Perform linewidth measurements on specimens using optical microscopy.

2001 Test revised models/definitions by iterating the fabrication, measurement, and model revision steps above.

2002 Develop one of the linewidth artifacts into a linewidth SRM.

Standards & Measurement Services

Standards Committees:

- ASTM E42.14

Metrology Education

Leader: Doiron, Theodore D.

Staff: Stoup, John R.

Total FTE .20

1998 MEL Goals Supported

5. Customer satisfaction and program recognition

Project Objective

Provide educational services to other metrologists, primarily hose in private industry.

Needs Addressed

There are almost no educational resources in dimensional metrology. There are only three community colleges that offer two year associate degrees in metrology, and no four year colleges at all.

Technical Approach

We have developed two different seminars: one, a two-day course on the general principles of Dimensional Metrology; and the other, a three-day seminar on Gage Block Calibration. In conjunction with the Gage Block Seminar, we have written a 150 page monograph. We have also given a number of 1/2-day tutorials on limited subjects such as cylinder calibration and the requirements of NCSL Z540-1 Calibration Laboratory Standard. We are also working with members of the Statistical Engineering Division as part of their two day seminar on measurement uncertainty.

We are also part of two nascent efforts to start metrology courses at the college level. Along with our colleagues at the Department of Energy Oak Ridge Metrology Center (ORMC) in Oak Ridge, TN, we are working with the Industrial Engineering faculty of North Carolina State A&T University to attract funding and equipment for a number of courses to be developed for their curriculum.

Prior Year Accomplishments

- The "Generic Uncertainty Budget for Dimensional Metrology" was published and widely circulated. It has been used by a number of industrial laboratories as the basis of their uncertainty budgets for NVLAP and A2LA accreditation.
- The first Dimensional Metrology Seminar, held in conjunction with the Measurement Science Conference, was held in Anaheim in January. The course was full, and we have been asked to give the seminar again next year.
- The Gage Block Seminar at the NIST Gaithersburg site was again filled (24 participants).

FY 1998 Plans

- Continue development of Group WEB page, updating the FAQ and planning a method to move some of the Gage Block Seminar material onto the WEB site.
- We will continue to work with our colleagues at NCS AT&T and ORMC to start programs which will provide metrology education at the college level.
- Begin planning series of topics for rotation with the Gage Block Seminar.
- Present Gage Block Seminar and Dimensional Metrology Seminar.
- Develop Measurement Science Conference session on material properties and dimensional metrology.

Five Year Plan Goals vs. Fiscal Year

2000 Assist UNCS AT&T in developing metrology courses

2001 Develop/Present Topical Dimensional Metrology Seminar

2002 Expand Group WEB page with current seminar material

2002 Present and revise DM Seminar at MSC meeting

2002 Present and revise Gage Block Seminar

Microform Metrology

Leader: Song, Junfeng

Stafff: Vorburger, Theodore V.

Total FTE: .55

1998 MEL Goals Supported

1. Laboratory research and development.
2. Physical-based National and International Systems of Standards and Measurements.

Project Objective

To develop NIST microform metrology including calibration systems based on both stylus and optical techniques, calibration and check standards, and calibration and uncertainty procedures. Based on the NIST microform calibrations, to develop the NIST standard Rockwell hardness diamond indenters as the U.S. national primary standard and the international common standard. To develop a metrology approach to unifying the U.S. and international Rockwell hardness measurements, and to overcome the international trade barrier. To support the US industry with the highest accuracy of the NIST microform calibrations, as well as help maintain the world leader position for international Rockwell hardness standardization.

Needs Addressed

Recent developments in computer science and technology, micro-electronics, and precision engineering, as well as U.S. and international standardization efforts for Rockwell hardness standards, have resulted in a new area in surface metrology, called microform metrology. In microform metrology, the complex 3-D surface features in the micrometer scale must be quantified for their shape and size including dimensions, curves, angles, profile deviations, and alignment errors, as well as surface roughness with measurement uncertainties compatible with tolerance requirements. One of the requirements for microform metrology comes from U.S. and international work in Rockwell hardness standardization. Rockwell C hardness (HRC) is the most widely tested materials property for metal products. Until the start of this project in cooperation with the Materials Science and Engineering Laboratory (MSEL), The United States had no national laboratory for Rockwell standards. Meanwhile, international comparisons including the U.S. showed significant differences in measured results of ±0.9 HRC. In contrast, during the 1980's, the European Community (EC) countries unified their HRC scales to ±0.3 HRC. With the development of the ISO 9000 quality standards, the unified EC scale is presenting a challenge to the United States. This technical barrier to trade will directly affect the $75 billion U.S. metal products industry, the $170 billion U.S. automobile industry, and the $93 billion aerospace industry, as well as machinery and many other industries. Both the ISO 9000 quality standards and international trade require NIST to develop the US national hardness facility into a world class facility to overcome the potential trade barrier and, therefore, to support U.S. industry.

Technical Approach

Because there was no metrology approach to verify precisely the geometric correctness of the Rockwell indenters, the EC HRC scales had to be unified through hardness performance comparisons. The performance-based EC scale lacks traceability to fundamental metrology, has an unknown bias to the correct scale, and lacks reproducibility, and therefore, cannot be used for unifying the U.S. and the international Rockwell scales. Based on the NIST microform calibration system using a stylus technique, a NIST approach was proposed to establish a metrology-based Rockwell standard system through the development of the NIST Standard-Grade Rockwell Diamond Indenters. Another microform calibration system using an optical technique is also proposed to verify these indenters. The NIST standard indenters, combined with the use of the NIST standard testing machine in MSEL's Metallurgy

Division and a standardized testing cycle, are proposed to create, maintain, and reproduce the metrology-based Rockwell hardness scale in the U.S. and overcome the unknown bias in the EC performance-based HRC scale. The NIST standard reference material (SRM) indenters and the NIST SRM hardness blocks (to be developed in MSEL) will transfer the established NIST metrology-based Rockwell hardness scale to U.S. industry, as well as to the world. The NIST metrology-based Rockwell hardness standard system will establish a worldwide unified Rockwell scale traceable to fundamental metrology.

Related Developments

Besides the NIST microform calibration system and the NIST standard Rockwell diamond indenters developed in the MEL, the related developments include the NIST standard Rockwell hardness machine and the NIST SRM Rockwell hardness blocks developed in the MSEL, as well as a standardized common testing cycle which will be developed by the ISO standards committee.

Prior Year Accomplishments

- Sponsored two successful NIST small business innovation research (SBIR) proposals for manufacturing of the NIST standard indenters. Worked with the U.S. and international diamond manufacturers for manufacturing the proposed NIST standard indenters
- Developed a group of 11 indenters with good geometry and hardness performance for the MSEL, one of them was used as the U.S. master standard for the calibrations of 300 NIST SRM 2810, 2811 and 2812 standard hardnessblocks
- Demonstrated the highest accuracy for the NIST microform calibrations by international comparisons. The international round robin supports the NIST approach to unifying the world- wide Rockwell scales
- Published four papers describing the NIST microform calibrations and the metrology approach, and received international support including national measurement labs in Italy, Germany, China, Japan, and UK as well as a leading state lab in Germany.
- Conducted technical talks in Finland, Spain and Taiwan. The NIST approach has received world- wide support and recognition
- Signed an agreement to participate in an international round robin sponsored by the European Community Bureau of Reference (BCR) and based on the NIST approach. The common indenters to be used in the study will be calibrated in the NIST
- Calibrated and tested 13 indenters from German and Japanese manufacturers, the National Research Laboratory of Metrology (Japan), the Nordrhein Materials Testing Lab (Germany) as well as U.S industry.

FY 1998 Plans

- Develop optical techniques for Rockwell indenter calibrations
- Upgrade measurement automation of NIST microform calibrations
- Continue work with U.S. and international diamond manufacturers for developing NIST standard indenters and SRM indenters
- Publish two NIST papers "Advances in the NIST Standard Rockwell Diamond Indenters," (HARDMEKO-98), and "NIST Microform Calibrations – How It Supports the U.S. Industry?" (ASPE-98)
- Publish two joint papers in cooperation with other four national laboratories entitled "Establishing A Worldwide Unified Rockwell Hardness Scale with Metrology Traceability" (Metrologia, Paris); "Establish A Worldwide Unified Rockwell Hardness Scale Using Geometrically Calibrated Standard Diamond Indenters." (Measurement, London)
- Participate in workshop with MSEL for U.S. industry regarding Rockwell hardness standardization

- Maintain the calibration accuracy and repeatability for the NIST master indenter as the U.S. primary standard; calibrate the common indenters to be used for the international round robin
- Participate in the national and ISO committees and the international round robin for establishing a worldwide unified Rockwell scale using NIST proposed metrology approach and the NIST calibrated standard Rockwell indenters

Five Year Plan Goals vs. Fiscal Year

1999 Complete certification of NIST SRM 2809 Rockwell Indenters

1999 Automate the existing NIST microform calibration system based on the stylus technique

2001 Develop a series of NIST Standard Grade Rockwell Indenters as US primary standards

2001 Develop an optical microform calibration system for microform calibrations at NIST

2002 Participate in an international round robin for a worldwide unified Rockwell standard

Standards & Measurement Services

SRM:

- SRM 2809: NIST SRM indenters (ISO 674 compatible); SRM 2810, 2811, 2812: NIST Rockwell blocks to be calibrated by the NIST primary indenters

Calibrations:

- NIST microform calibrations for US industry

Testing:

- Special testing for Rockwell indenters

Committees:

American Society for Testing and Materials (ASTM) E18 and ISO TC 164: Hardness testing

Molecular Measuring Machine

Leader: Kramar, John A.

Staff: Chen, Tsan-Lin
Eom, TaeBong
Howard, Lowell P.
Jun, Jau Shi
Penzes, William B.
Scire, Fredric E.
Villarrubia, John S.

Total FTE: 3.70

1998 MEL Goals Supported

1. Laboratory research and development.
2. Physical-based National and International Systems of Standards and Measurements.

Project Objective

To develop and operate a coordinate-measuring machine that features sub-nanometer probe resolution and one nm total uncertainty within a measuring volume of 50 mm x 50 mm x 0.1 mm in order to produce calibrated artifacts, provide calibration services, and develop improved measurement techniques in support of U.S. industry--particularly the semiconductor manufacturing industry--in its needs for line width, pitch, and especially 2D point-to-point metrology.

Needs Addressed

The Molecular Measuring Machine (M^3) was conceived and developed in direct response to deficiencies in measurement capabilities at NIST that are projected to be a serious limiting factor in certain high technology industries. At the time the project was started, the minimum uncertainty in line spacing measurements at NIST was 10 nm for line spacing from 5 mm to 50 mm and only 25 nm for line spacing of 1 µm to 50 µm. Physical linewidth measurement uncertainties were about 50 nm for linewidths ranging from 0.5 µm to 10 µm. The U.S. microelectronics, data storage and precision optics industries have repeatedly requested that NIST reduce the measurement uncertainties of these quantities to the sub-nanometer range. These requests are motivated by the availability of commercial instruments with resolutions as high as 10 pm, and by the increasingly smaller critical dimensions in microelectronics circuit elements and in mass storage media and devices. As a specific example, for the year 2001, the Semiconductor Industry Association's National Technology Roadmap for Semiconductors is calling for an image-placement accuracy of 32 nm and a critical-dimension mean-to-target accuracy of 10 nm for critical-level lithography masks. For process control, the metrology uncertainty will need to exceed these values by a factor of 10.

Technical Approach

Our response has been to build and operate the NIST Molecular Measuring Machine (M^3), a state-of-the-art, two-dimensional, coordinate-measuring machine designed to achieve 1 nm total uncertainty for point-to-point measurements over a 50 mm x 50 mm area while accommodating surface height variations of as much as 100 µm. The sensing probes are scanning tunneling and atomic force microscopes, which give an imaging resolution that extends to the atomic (sub-nanometer) scale. The displacements are measured with a custom-built, state-of-the-art, heterodyne interferometer having a measurement resolution of 10 pm with a 2 kHz bandwidth. In order to achieve these metrological goals the instrument incorporates high performance seismic and acoustic vibration isolation systems, an ultra-high vacuum system, and an advanced temperature control system capable of maintaining a temperature stability of 0.1 mK. This instrument will provide most of the aforementioned measurement capabilities requested by the U.S. precision optics and microelectronics industries. It will be used to measure line spacing, linewidth, and feature-placement artifacts that can be used to calibrate the industries' measuring machines. In addition to providing these metrological capabilities and services, M^3 will also be used as a tool for exploratory research in the rapidly growing field of nanotechnology.

Prior Year Accomplishments

- Iteratively assembled, tested and modified the design of the Z-axis, coarse-motion motor.
- Developed Lab View software programs for testing the motion errors of the motion generation systems, and for testing new piezoceramic stepping-motor designs.
- Improved the cleanroom facility by procuring cleanroom compatible furnishings and a particle monitoring instrument.
- Evaluated alternative architectures, designed, and purchased hardware and development-software components for a new data-acquisition, instrument-control, and image-processing system.
- Evaluated alternatives, designed, purchased components, assembled, and demonstrated the successful performance of new X and Y coarse-motion motors.

FY 1998 Plans

- Re-measure standard reference material (SRM) 2800 prototype #7 and some laser focused atomically deposited (LFAD) chromium gratings to evaluate the effect of the M3 instrument upgrades that are being made.
- Design and install more robust links for the Mallock suspension in the active vibration isolation system. The links will include actuators for vibration cancellation.
- Design, assemble, test and install a new Z-axis motion assembly that includes: (1) a coarse motion motor redesigned for greater reliability, with a coarse position sensor; (2) a fine motion actuator that incorporates motion guides for improving repeatability and linearity to 10 nm; (3) a capacitance gage that will provide 1 nm resolution metrology for the Z axis fine motion; and an orthogonal superfine XY scanner for imaging samples using the fast-scan mode.
- Port the data-acquisition, instrument-control, and image-display software to the new computer system, writing new software where necessary.
- Replace the M3 machine core with the new core that has single-point diamond machined ways. This will minimize the run out of the coarse motion carriages and should lead to better overall measurement accuracy.
- Replace the stainless-steel probe/interferometer mounting plate with one made of Invar in order to decrease the effects of temperature variations by a factor of ten.
- Install the low-power, high-force actuators for the X and Y coarse motion carriages.
- Design and install capacitance gages for measuring the position of the fine motion carriages relative to the coarse motion carriages for the X and Y axes with a precision of about 10 nm. This capability is necessary for error mapping the fine motion carriages and thereby improving the overall positioning repeatability.

Five Year Plan Goals vs. Fiscal Year

2000 Port the existing data acquisition software to the new control computer and continue to refine it to develop new capabilities and make it more reliable, more easily taught to new operators, less prone to operator or system errors, and more thoroughly documented.

2001 Develop specific procedures for measuring the repeatability of motion and for creating an error map of the M3 motion generation systems. Error map the motion systems. Develop scan algorithms that will reference the error maps and produce error corrected scans.

2002 Provide measurement services to customers by calibrating existing artifacts and developing and calibrating new artifacts.

1999 Install an iodine stabilized laser as a stable frequency source which to monitor the frequency and hence wavelength of the metrology lasers.

2000 Increase the versatility of M3 by modifying the probe system to include an atomic-force microscope.

2000 Design, install and test a six-degree-of-freedom, active, vibration-isolation system for M3.

2001 Evaluate the tribological performance of candidate load-bearing pads for use on the M3 diamond-turned slideways. Then exchange the current pad/slideway system for this improved combination.

Standards & Measurement Services

Testing:

- Special testing on artifacts performed at the request of NASA.

NIST Line Scale Interferometer Upgrading

Leader: Penzes, William B.

Staff: Beers, John S.
Jun, Jau Shi
Scire, Fredric E.

Total FTE: 1.15

1998 MEL Goals Supported

1. Laboratory research and development
2. Physical-based National and International Systems of Standards and Measurements

Project Objective

To maintain NIST capability for line scale measurements at a world-class level. This project supports the goals of MEL as pinnacle of traceability and advanced measurement needs.

Needs Addressed

The line scale interferometer (LSI) serves a pivotal role in NIST measurements of the distance between two features - line scale measurements - for distances ranging from two µm to one m. It supports advanced measurement needs of the integrated circuit industry by providing calibrations of reticles for photo and X-ray masks, as well as line scale calibrations for optical line scale artifact manufacturers and manufacturers of various type of grid plates. Some of the U.S. corporations often requesting ultra-high accuracy line scale measurements are International Business Machines (IBM), American Telephone and Telegraph (ATT), Boeing Co, ACU-RITE, Corning, Inc., AMP, Inc. and Master Images. It remains the NIST reference for international practical comparisons of the meter. Finally, it serves as the NIST internal practical tie to the ISO definition of the meter for gage block measurements, ball-bar measurements, optical and scanning electron microscope (SEM) linewidth measurements and electrical test structure measurements. This project addresses four areas of improvement: (1) increasing the line detector resolution, (2) upgrading of the data acquisition and control computer system and interfaces, (3) improving the resolution and accuracy of the displacement interferometer, and (4) improving the mechanical structure to permit simultaneous comparison of the wavelengths of two lasers. For the first area, the LSI presently uses a scanning photo-electric microscope capable of measuring scales with linewidth of 1µm to 100 µm wide. The addition of a scanning capacitance line detector (SCLD) to the LSI will enable measurement of scales with graduation linewidths as narrow as 10 nm. The other improvements should be self explanatory when combined with the milestones and five-year plan.

Technical Approach

To develop a scanning capacitance line detector (SCLD), a design based on a successful earlier NIST design is being built and tested. In this design the detector capacitor is placed in one leg of a carrier operated series resonant bridge. The line detector sensitivity depends on the carrier frequency, the stand-off distance, the tip diameter, the detectable line width and the quality factor of the bridge components. The effect of all these parameters are currently being investigated experimentally and theoretically. Upgrading the data acquisition and control computer system will use a new high performance personal computer (PC), making all the necessary hardware modifications, redesigning the measurement procedure, rewriting the data acquisition and control software, installing a new data acquisition, data analyzing, instrument control and advanced graphic software. Interferometer improvements planned will include adaptation of the phase measurement improvements from M^3. After acareful design study, some means to overcome uncertainties from index of refraction effects will be included.

Prior Year Accomplishments

- Some of the Lab View drivers for the different interfaces and peripheral instruments were developed, installed and tested.
- The National Instrument Lab View graphical software was purchased and installed.
- The new Hewlett Packard (HP) 5517A laser and its control card was installed, configured. The new interferometer was installed and tested, a Lab View based program was developed to read the laser.
- Some new thermocouples were installed and tested with the new Keithley scanner system.
- The 20 °C reference platinum resistance thermometer (PRT) was connected to the Keithley 2002 instrument and to the L&N Bridge with the isothermal switch and the two readings were monitored and compared.
- A four pole double through isothermal switch ws fabricated and installed.
- The digital to analog (D/A), analog to digital (A/D) data acquisition board was purchased, installed, configured, and tested.
- The 192 line input/output (I/O) interface board was purchased, installed, configured and tested.
- A new 16 bit IEEE488 interface board was purchased and installed into the LSI PC.
- Completed the electronic and mechanical designs and assembled of SCLD using planned 100 MHz circuit design.
- The new and old HP lasers kinematic mount adapters were fabricated by the shops and they were installed.
- Designed, received cost estimate, and ordered the manufacturing of a four inch diameter, 2 1/2 m long and 6 mm wall thickness Super Invar tube for the LSI scanning microscope support bridge.
- A 2.5 GB hard disk drive was purchased and installed into the LSI PC.

FY 1998 Plans

- Make preliminary measurements with the 100 MHz SCLD system and evaluate the results.
- Make several comparison measurements with the old HP computer system and the new PC system.
- Develop the whole operational data acquisition and control computer program for the LSI with Lab View. Run and de-bug the program if necessary.
- Write several subroutines using Lab View for the LSI PC length measuring process.
- Write (modify) the Lab View controllers for all sub-systems and peripheral instruments.
- Make all connections between the LSI line centering servo electronics, the stepper motor controller, the HP 5500 Laser display unit and all peripheral instruments with the interfaces to the LSI PC.
- Connect all thermal couplers (TCs) to the new Keithley 705 scanner and measure the outputs with the Keithley 182 Nanovoltmeter and analyze the data.
- Calibrate all TC-s with an isothermal block in the LSI chamber.
- Find a machine shop which will be able to do the machining work on the Super Invar tube to specifications.

Five Year Plan Goals vs. Fiscal Year

1998 Upgrade LSI computer and interfaces to peripherals.

1998 Install new temperature data acquisition and control electronics for LSI.

1999 Complete the mechanical modifications of the LSI to enable dual wavelength comparison.

1999 Do preliminary measurements with 100 MHz SCLD and compare the results of the 10 MHz probe.

1999 Write LSI new data acquisition and control computer program.

2000 Furbish the LSI with Iodine Stabilized Laser to increase measurement capability and accuracy.

2000 Upgrade LSI control electronics by converting all existing prototype circuit boards to printed circuit boards.

2001 Design standard reference material (SRM) for length standards which can be measured by optical, electrical test structure and capacitive sensing methods.

2002 Design, construct a SCLD for LSI utilizing integrated circuit electronics.

2002 Conduct design study to evaluate relative advantages/disadvantages of using interferometer path in vacuum, controlled gas environment, and two color index of refraction measurement.

Standards & Measurement Services

Calibrations:

• line scale, grid plates, end standards

Optical Photomask Metrology

Leader: Potzick, James E.

Staff: Snoots, Patricia A.

Total FTE: .45

1998 MEL Goals Supported

2. Physical-based National and International Systems of Standards and Measurement
5. Customer satisfaction and program recognition

Project Objective

Maintain and improve quality of SRM 473, SRM 475, and SRM 476 photomask linewidth standards and their availability to industry. Develop SRM 2059 that is the successor to SRM 473.

Needs Addressed

As the United States' national standards laboratory, NIST provides Standard Reference Materials (SRMs) to meet industry calibration and traceability needs.

Accurate measurement and control of feature sizes on integrated circuit (IC) photomasks is critical to current and advanced IC manufacturing processes. This photomask linewidth SRM is the established standard for linewidth measurement among photomask vendors and users. Required calibration uncertainty is expected to decrease, market demand is expected to increase, and stock must be maintained.

Technical Approach

Specify and procure high quality photomasks for the current NIST photomask linewidth standard SRM 473; inspect, calibrate using the NIST Ultraviolet microscope, maintain records, package and deliver to Office of Sandard Reference Materials for distribution to users. Take steps to reduce calibration uncertainty.

Confer with industry users on the design of a new photomask linewidth standard, SRM 2059, to replace SRM 473. Identify a mask manufacturer willing and able to meet the stringent specifications for SRM 2059, and procure and evaluate prototype samples.

Prior Year Accomplishments

- Replenished supply of SRM 473.
- Conferred with industry representatives on design of new photomask SRM.

FY 1998 Plans

- Design new photomask linewidth SRM 2059 to meet current industry needs.
- Identify vendor. Procure and test prototype samples of SRM 2059.
- Procure first batch of SRM 2059. Commence calibrations on the Ultraviolet Microscope.

Five Year Plan Goals vs. Fiscal Year

1999 Extend minimum certified linewidth to 0.25μm on SRM 2059.

1999 Complete transition of calibrations to the Ultraviolet Microscope.

2002 Maintain collaboration with the European Economic Community and other national laboratories in optical linewidth measurement.

Standards & Measurement Services

SRM:

- SRM 473
- SRM 2059

Committees:

SEMI Microlithography Standards Committee, SEMATECH Mask Advisory Steering Council

Overlay Metrology

Leader: Silver, Richard M.

Staff: Kornegay, Edward A.
Larrabee, Robert D.
Potzick, James E.
Scire, Fredric E.

Total FTE: 1.30

1998 MEL Goals Supported

1. Laboratory research and development
2. Physical-based National and International Systems of Standards and Measurements

Project Objective

Design and implement an optical based overlay metrology system for the study and calibration of feature overlay on silicon wafers resulting from two or more patterning steps in integrated circuit (IC) fabrication. To design, procure, and calibrate Si based standards in support of overlay metrology.

Needs Addressed

NIST is responsible to the U.S. microelectronics industry for developing calibration standards in support of semiconductor IC production. With many fabrication lines turning out more than 2000 wafers per week and over 100 die per wafer, improvements in metrology can often improve yield that translates into substantial financial gains. Metrology issues are particularly critical in overlay measurement since the reduction in feature sizes of very large scale integrated (VLSI) circuitry puts increasing demands on pattern placement of one level relative to another. This is widely recognized as one of the primary elements of concern in yield management. NIST currently offers no overlay standards and there is, consequently, an immediate need for the development of overlay calibration instrumentation and standard artifacts.

Pattern placement of the various levels is typically monitored through a series of box-in-box patterns, each in a different plane. The overlay offset is determined by optical measurements of the box center lines where each box is in a different plane. Any misalignment in the overlay metrology system will translate into an artificial overlay offset, referred to as Tool Induced Shift (TIS). Additionally, there are residual errors caused by asymmetries in the box, in box edges, or covering layers (resist) known as wafer induced shift. A set of standard artifacts and procedures needs to be developed to align overlay measurement systems and eliminate TIS. Similarly, the aligned instruments must then be calibrated with standard artifacts to yield accurate overlay offsets.

Technical Approach

The technical strategy is divided into two segments: 1) instrumentational development and overlay metrology methodology, and 2) design and calibration of standard artifacts. The measurement system is designed for maximum accuracy and repeatability (high throughput is not essential for the NIST calibration system). The system is an optical-reflection-mode instrument, operational in either a bright field or confocal mode, with interferometry on three orthogonal axes also capable of monitoring the stage tilt. Additional instrumentational requirements are the option to scan the sample in any one of the three orthogonal axes, the ability to rotate the sample, and fully automated image recognition. Proper optical alignment in the z-direction is critical. Similarly, precise stage motion is essential to ensure that z-axis focusing motion is decoupled from x- and y-axis motion since this will also add an erroneous shift to the image.

The first aim of the NIST standards program is to develop better methods to characterize tool induced shift (TIS). The goal is to ensure that the overlay tool is operating within an appropriate TIS specification. This will be accomplished by the development of a "tool kit" with procedural and artifact standards to assist in alignment of the optical and mechanical elements of the overlay metrology system. These tools would allow calibration of residual X- and Y- motions during focusing in the Z-direction, adjustment and alignment of the illumination source, and calibration of the charge coupled display (CCD) pixels. Once the tool is aligned and TIS free, it may be used to characterize wafer induced shift of the test specimen.

Preparation of standard artifacts for this purpose is the second goal of the NIST program. Since user test patterns frequently have asymmetries in the edges and covering layers that are user specific, the NIST approach is to develop calibrated, wafer-induced, shift-free standard artifacts. The edge geometry of these samples may be verified by scanning electronic microscope (SEM) or atomic force microscope (AFM) techniques. The final result would be wafer-induced, shift-free standards for the calibration of TIS free optical overlay tools. The overlay artifacts are currently in the design phase and the final result is intended to be wafer-induced, Shift-Free Standards for the calibration of TIS free optical overlay tools. These artifacts will be fabricated in single crystal silicon with selective etch methods or perhaps with conventional dry etch if satisfaction edges can be obtained.

The system is capable of large distance scans to 90 mm (3.5 in) in the x and y directions without compromising the interferometry accuracy or the structural rigidity. Materials used in the metrology loop and the mechanical components were chosen to minimize thermal effects on the measuring process. Since thermal effects become the dominant error for long distance scans, the accuracy of these measurements can be substantially enhanced with a temperature control system. The addition of such a control system will make this instrument capable of state-of-the-art two-dimensional grid measurements.

Prior Year Accomplishments

- Performed calculations using the Spectel model. Performed experimental comparison with Spectel simulation output on the stepped microcone artifact. This analysis was very useful in illuminating a number of simulation code inadequacies.
- Developed software for automatic image analysis and edge detection using Matlab. Completed the first round of image analysis and filtering software.
- Developed a significant portion of the control code for automatic data acquisition.
- R. Silver participated in the Semiconductor Equipment Manufacturers International (SEMI) standards committee as task force leader on overlay metrology and two-dimensional grids and calibrations.
- Complete the installation and alignment of the 2-dimensional interferometry system.
- Completed the construction and demonstrated initial measurement capabilities.
- Present paper at SPIE on the NIST overlay metrology project and initial measurements of the first overlay tool alignment artifact.
- Began the process of system evaluation with measurements of stage runout, lateral coupling, and optical image analysis.
- Several key issues in overlay metrology were investigated and the designs for the initial overlay standard artifacts were completed. Prototype alignment artifacts (stepped microcone) were manufactured with preliminary analysis complete.

FY 1998 Plans

- Design and procure metrology photomask. Work with Industry partners to determine designs and which levels are most appropriate for the silicon fabrication phase.
- Design 2-dimensional grid artifact. Procure mask and make measurements with applications of the self-calibration algorithms.
- Perform measurements to improve overlay measurement techniques on industrially relevant samples. Compare measurements of overlay target structures with key industry partners.
- Participate in the SEMI standards committee as task force leader on overlay metrology and two-dimensional grids and standards.

- Develop comprehensive modeling capabilities for centerline and edge detection methods. This is completed in connection with Spectel Co. and SEMATECH.
- Investigate the key issues in overlay metrology and complete the design of the second phase of overlay standard artifacts. Submit proposal to SRM office for funding.
- Complete the formal qualification process of the microscope optics and the x-y metrology.

Five Year Plan Goals vs. Fiscal Year

1998 Complete image recognition software, full analog and digital filtering, and internal graphics capabilities. (OMP, STRS).

1998 Investigate effects of covering layers, resist, and material thicknesses on apparent overlay shifts. (STRS).

1999 Acquire overlay standards (both alignment and calibration) for SRM certification. (SRM Office).

1999 Develop modeling techniques for edge analysis and pitch determination, in the reflection mode, necessary for overlay measurements. (OMP, STRS).

2000 Participate in development of reflection mode optical linewidth measurements and modeling techniques. (OMP, STRS).

Standards & Measurement Services

Committees:

- 2-Dimensional Grid Task Force
- Microlithophry Committee of Overlay Standards Work
- SEMI Group

Quality System Project

Leader: Hartsock, Ronald G.

Staff: Doiron, Theodore D.
Everett, Dennis S.
Faust, Bryon S.
Fronczek Jr., Charles
Fu, Joseph
Land, Janet L.
Penzes, William B.
Potzick, James E.
Stanfield, Eric S.
Stocker, Michael T.

Total FTE: .85

1998 MEL Goals Supported

2. Physical-based National and International Systems of Standards and Measurements
5. Customer satisfaction and program recognition

Project Objective

The objective is to provide documentation for the Calibration Laboratory based on conformance with American National Standards Institute/National Conference of Standards Laboratories (ANSI/NCSL) Z540.

Needs Addressed

The target customers are those companies that send their dimensional artifacts to NIST for calibration. NIST, through National Voluntary Laboratory Accreditation Program (NVLAP), will begin to accredit calibration laboratories to the U.S. version of ISO Guide 25 (NCSL Z540-1). We are documenting our current quality system in the fashion of the international standard, which provides us with adequate documentation for our own uses and acts as a model for outside high-accuracy laboratories.

Technical Approach

We will create procedures based on current practices, documenting the current quality system to provide policies and objectives We will develop procedures for parts of the standard for which we currently do not have formalized systems in place. This is a continuing project.

Prior Year Accomplishments

- Completed a survey of SP-250 Calibrations in PED.
- Completed Quality Manual in draft form.
- Continued writing the operating policies and procedures for PED Calibration laboratories.
- Began implementing the ANSI/NCSL Z540 for PED Calibration laboratories.

FY 1998 Plans

- Complete Quality Manual.
- Continue writing the operating policies and procedures.

Five Year Plan Goals vs. Fiscal Year

1998 Complete Quality Manual.

1998 Finish writing procedures and work instructions.

1998 Refine ANSI/NCSL Z540-1 requirements.

2001 Satisfy requirements for compliance to ANSI/Z540.

Standards & Measurement Services

SRMs:

In process of implementing a quality system for SRMs and calibrations to satisfy ANSI Z540- NCSL Z540.

Calibrations:

In process of implementing a quality system for SRMs and calibrations to satisfy ANSI Z540- NCSL Z540.

Scanning Electron Microscope Dimensional Metrology

Leader: Postek, Michael T.

Staff: Carroll Jr., Clarence Leon
Jones, Samuel N.
Keery, William J.
Larrabee, Robert D.

Total FTE: 2.00

1998 MEL Goals Supported

1. Laboratory research and development
2. Physical-based National and International Systems of Standards and Measurements

Project Objective

The scanning electron microscope (SEM) is used in many phases of manufacturing. This instrument is used extensively in the semiconductor industry in the manufacture and quality control of semiconductor devices. The National Technology Roadmap for Semiconductors targets scanning electron microscopes as the metrology tool of choice for use in semiconductor production up through at least the year 2003. The objectives of this program are to develop standards, specifically those related to instrument performance and the measurement of linewidth, for the scanning electron microscope. This entails a multidimensional program including: artifact fabrication, understanding the function and signal generation in the SEM, developing NIST metrology instruments for the certification of standards, and developing the necessary artifacts and calibration procedures.

Needs Addressed

The manufacture of present-day integrated circuits requires that certain measurements be made of the submicrometer structures composing the device with a high degree of precision. The accuracy of these measurements is also important, but more so in the development and pilot lines. The measurements of minimum feature sizes known as critical dimensions (CD) are made to insure proper device operation. NIST is responsible to U.S. industry for developing length intensive measurement capabilities and calibration standards. This project supports all aspects of this need since scanning electron microscopy is the major microscopical technique used for this submicrometer metrology. NIST addresses this need by providing (or is currently developing) standards and measurement techniques for these measurement instruments.

Technical Approach

The development of SEM linewidth standards is a multidimensional project. This project is being tackled through several thrusts, fully supported by the semiconductor industry. The major areas (each with several subareas) are described.

Standard Reference Material (SRM) 2090: Primary to SEM dimensional metrology is the calibration of the magnification of the instrument. SRM 2090 is an SEM magnification standard that will function at the low beam voltages used in the semiconductor industry, high beam voltages used in other forms of microscopy and will have capability down to 0.2 µm pitch. A prototype with 0.2 µm lines and spaces was fabricated by the Nanofabrication Facility at Cornell University as a proof of concept and was used in a round robin study that clearly demonstrated the need for this standard. Texas Instruments was contracted to supply the first production run of the artifact with 0.1 µm lines and spaces and delivered over 180 of these research artifacts. In order to speed the availability of this artifact to the industry (while the final certification details are being completed) the artifact has been released to the industry as Research Material 8090.

Sharpness Standard: The performance characteristics of the SEM are extremely important to precise and accurate metrology. A sharpness standard and evaluation procedure is being developed to monitor (or compare) SEM image quality. It is based on etched, biphasic glass or an etching defect called "grass." NIST is working with Texas Christian University on its development, Spectel Company on a user-friendly analysis system called SEM Monitor and with SEMATECH and the industry on the use of this standard and procedure in the production environment. The "ISAAC" SEM image analysis system previously developed at NIST was used initially to analyze the images obtained from the test samples. More recently, Spectel Company has released a workstation product utilizing the NIST technology providing a quantitative method for instrument evaluation.

Monte Carlo Modeling: Improvements are being made in the previously developed Monte Carlo computer model of beam-electron interaction with the sample that leads to a theoretical prediction of the SEM image profile of a feature. This model was originally developed to find edge location criteria for use in measuring the submicrometer features on masks used in x-ray lithography. The model has now been extended to include profiles of secondary and backscattered-electrons, as well as, the original transmitted. Work has progressed to include multiple parallel lines (to study proximity effects), and to include 3- dimensional objects (such as vias). NIST is currently collaborating with Digital Equipment Corporation, Spectel Company and SEMATECH to include the characteristics of production SEMs into the model for the purpose of verification and comparison to actual experimental and production line data.

NIST/National Advanced Manufacturing Testbed (NAMT) Telepresence: A NIST/NAMT telepresence web site has been established at http://scanner.cme.nist.gov to promote research and technology transfer via the Internet.

Combined SEM/SxM: Metrology at the nanometer level requires an intimate knowledge of the characteristics and the position of the edges being measured. A proof of concept measurement instrument combining a SEM and a commercially available scanned probe instrument will be placed in operation to investigate and facilitate comparison measurements.

Prior Year Accomplishments

- Developed and published a robust analysis algorithm based on kurtosis for the analysis of SEM sharpness.
- Initiated contracts to Texas Christian University and the University of Texas for the development of the SEM sharpness artifacts.
- Succeeded in moving the SEM laboratory to the basement of the Metrology Building.
- Participated in the Internet Delivery of Measurement Services task force.
- Initiated a contract for the fabrication of SRM 2090 artifacts using x-ray lithography.
- Began comparative measurements between the combined SEM/SxM metrologies.
- Compared the measured AT&T (Lucent Technologies) SCALPEL mask data to the electron beam model data and presented the results.
- Actively participated in the linewidth correlation study.
- Investigated the contribution of charging upon apparent beam-broadening in the SEM.
- Demonstrated the utility of the NIST/Spectel/Hewlett-Packard sharpness procedure and developed a user-friendly production analysis system.
- Obtained a SEMATECH contract to study high accuracy critical dimension metrology for semiconductor manufacturing.
- Tested and redesigned the state of the art motorized SEM stage in collaboration with small business.

- Implemented a telepresence for the SEM in the new laboratory facility in the Metrology building (http://scanner.cme.nist.gov).
- Participated in the development of the PED Benchmarking document.

FY 1998 Plans

- Achieve delivery and installation of six inch wafer SEM donated by Texas Instruments.
- Continued support of Cooperative Research and Development Agreement (CRADA) partners (Topometrix, IBM, E. Fjeld) and SEMATECH.
- Improve the accuracy of thick layer metrology of photoresist structures.
- Collaborate with Texas Instruments on an "IDEA" Program to demonstrate the value of microscopy via the Internet.
- Implementation of a telepresence capability for the SEM/SxM and the x-ray microanalysis system in the new laboratory facility using the NIST-asynchronous transfer mode (ATM) network in support of NAMT.
- Fabricate the SEM sharpness standard and prepare for release by Standard Research Materials Program (SRMP). Obtain delivery of SRM 2090 artifacts, complete the SP 260 for SRM 2090 and issue the standard.

Five Year Plan Goals vs. Fiscal Year

2000 Develop and issue thick layer SEM linewidth standard.

2000 Improve the accuracy of thick layer metrology of photo-resist structures using the application of Monte Carlo modeling and associated experimentation.

2000 Attempt comparative measurements between SEM and SPM metrologies using the new combined instrument (STRS, OMP)

2002 Continue SEMATECH interactions

2002 Acquire production batches of SRM 2090 certify and issue the standard (STRS, OSRM, OMP).

2002 Acquire environmental microscope to facilitate the study of specimen charging and high aspect SPM tip generation.

2002 Upgrade SEM metrology equipment and methods for large sample (300mm) metrology - SEM/SPM system (OMP, STRS).

Standards & Measurement Services

SRM:

- RM 8090 predecessor to SRM2090
- SRM 2090 SEM Magnification Standard
- SRM 2091 SEM Sharpness Standard

Committees:

ASTM F1, SEMATECH Advanced Metrology Advisory Group

SEMATECH Liaison

Leader: Postek, Michael T.

Total FTE: .20

1998 MEL Goals Supported

1. Laboratory research and development
2. Physical-based National and International Systems of Standards and Measurements
5. Customer satisfaction and program recognition

Project Objective

SEMATECH is a consortium of U.S. semiconductor manufacturers. The purpose of this project is to maintain a working relationship with SEMATECH and its member companies targeting the measurement needs of the semiconductor industry relative to the dimensional measurement capabilities of the Precision Engineering Division. The continuing purpose of this program is for NIST to apply its metrology knowledge to selected SEMATECH lithography and metrology development activities. The targeted measurement technologies are: scanning electron microscope metrology, optical metrology, and scanned probe metrologies. This program is well within the charter and mission of NIST, and such collaboration is the best way for SEMATECH to achieve the key metrology objectives necessary for the success of current and future lithography programs at SEMATECH and its member companies.

Needs Addressed

The manufacture of current integrated circuits requires that certain measurements (e.g. linewidth, line spacing, and overlay), be made of the submicrometer structures composing the circuits with a high degree of precision. The accuracy of these measurements is also important, but more so in the development and pilot lines. The measurements of minimum feature sizes known as critical dimensions (CD) are made in order to insure proper device operation and as an indicator of manufacturing process stability. NIST is responsible to U.S. industry for the development of length intensive measurement capabilities and calibration standards. This project supports all aspects of this need. Optical metrology, scanning electron microscopy and scanned probe microscopies are the major techniques used for this submicrometer metrology. NIST addresses this need by providing (or currently developing) standards and measurement techniques for these measurement instruments.

Technical Approach

NIST will maintain a working relationship with SEMATECH through representation at appropriate technical advisory board meetings. NIST will assist SEMATECH and its member companies with its technical expertise in lithometrology and propose projects for SEMATECH collaboration and funding in areas where NIST can bridge the identified gaps between the expressed needs and present capabilities.

Related Developments

Continued SEMATECH other agency (OA) funding is unlikely due to a fundamental change in the funding structure and direction of SEMATECH. However, it is imperative that NIST maintain a liaison with SEMATECH because of its importance in the semiconductor industry. The project leader participates on several SEMATECH working groups and technical advisory boards.

Prior Year Accomplishments

- Held a combined NIST/SEMATECH workshop at the SCANNING meeting on quantitative instrument modeling.
- Obtained a SEMATECH contract of SEM Metrology and Overlay Metrology.
- Participated in the development of the National Technology Roadmap for semiconductors.

FY 1998 Plans

- Develop and present advanced SEM tool specifications at International Society for Optical Engineering (SPIE) and to the manufacturers.
- Continued collaboration with SEMATECH and the member companies.
- Completion of the SEMATECH contract.
- Participate in the Advance Metrology Group meetings for the development of new SEM tools for semiconductor production.

Five Year Plan Goals vs. Fiscal Year

2002 Continue interactions with SEMATECH and maintain a NIST presence at necessary SEMATECH functions.

Standards & Measurement Services

SRMs:

- RM 8090 predecessor to SRM2090
- SRM 2090 SEM Magnification Standard
- SRM 2091 SEM Sharpness Standard

Committees:

ASTM F1, SEMATECH Advanced Metrology Advisory Group

SPM Tip Preparation and Characterization

Leader: Silver, Richard M.

Staff: Jensen, Carsten Povl
Kramar, John A.
Tsai, Vincent

Total FTE: 1.30

1998 MEL Goals Supported

1. Laboratory research and development.
2. Physical-based National and International Systems of Standards and Measurements.

Project Objective

This project is developing techniques for the preparation of scanning probe microscope (SPM) tips with reproducible geometries and the direct characterization of the SPM tip geometry and dimensions. These well-characterized probe tips will then be used to measure samples with photolithographically-defined or canonically-ordered surfaces on the nanometer length scale followed by a determination of their performance in these dimensional measurements.

Needs Addressed

NIST is responsible to U.S. industry for developing length intensive measurement capabilities and calibration standards in the nanometer scale regime. The new class of scanned probes have unparalleled resolution and offer the most promise for meeting these needs of the microelectronics industry. However, before this resolution can be translated into precise, accurate dimensional measurement capabilities, the scanned probe instruments must be fully calibrated. This requires accurate, dimensional characterization of SPM tips.

All images obtained with a scanned probe microscope are a convolution of the sample being measured, the SPM tip geometry, and any tip-sample interactions. As a result, SPM linewidth measurement uncertainties are dominated by the uncertainty in tip shape. On the macroscopic scale tip shapes can vary by 10 µm to 20 µm while the microscopic geometry is often uncontrollable. These variations in tip geometry and the inability to accurately measure tip dimensions are a major limitation to measurement accuracy and are the primary concern of SPM industrial users. The tip shape also has a profound effect on measurement stability and tip longevity as is often seen in pitch calibrations. These adverse effects are frequently encountered in NIST measurement instruments such as molecular measuring machine (M^3) and the calibrated atomic force microscope (AFM). These measurement limitations are addressable.

The key to accurate metrology is to develop methods for the production of known reproducible tip shapes, to accurately measure of tip geometry, and create models which interpret imaging data to extract real feature dimensions. NIST is currently developing the means for the reproducible production and characterization of SPM tips, such as the field-ion-field-electron microscope (FIFEM). The FIFEM will enable us to put an approximately 5 nm uncertainty on the geometrical shape of a tip with a 50 nm radius. This instrument can also be used for field evaporation that produces tips with controlled microscopic geometries. This project is focused on the systematic correlation of FIFEM results with SPM measurements to be performed in parallel with conventional scanning electron microscope (SEM) and optical measurements. An additional result of this project is the development of standard artifacts to verify tip performance and surface reconstruction procedures. We are performing a comprehensive study on the relationship between tip fabrication, cleaning processes and tip performance.

Technical Approach

The technical strategy can be broken into three thrust areas: 1) tip preparation and direct geometrical tip characterization

(FIFEM, SEM), 2) characterization artifacts (atomically ordered surfaces, nanometer scale defined topography, e.g. linewidth samples), and 3) modeling (extract physical feature dimensions, determine tip geometry).

We are focussing our efforts on two tip materials, Platinum Iridium and Tungsten. The strategy is to develop Platinum Iridium and W tips for systematic measurements on atomically ordered silicon surfaces. We are developing the scanning tunnelling microscope (STM) tip etching, field evaporation, and cleaning procedures which reliably yield stable W tips and produce atomic resolution on Si (7x7) surfaces. We will develop the necessary cleaning procedures, both in-situ (blast mode) and ex-situ, which allow transportation of the tips between the various SPM's at our disposal. This project will proceed in parallel with the existing effort at NIST for the comprehensive development of nanometrology capabilities. Specifically, the results from the measurements will be used by the current effort to extract physical feature dimensions and provide an accurate means of measuring topographical features (e.g., 100 nm linewidths or 1 nm step heights). The primary tools for direct tip characterization will be the FIFEM for 1 to 100 nm radii tips, and SEM analysis for larger tip features. We will make an effort to determine which new methods (e.g., transmission electron microscope (TEM)) can be developed to enhance the overlap region of these techniques.

For sample preparation, we are utilizing the existing in-situ processing apparatus and techniques from the ultra high vacuum (UHV) STM and concentrate on the reproducible production of atomically ordered Si surfaces and Si (111) step and terrace structures. The use of these canonically ordered surfaces will also enable us, in future measurements, to delineate physical/chemical interactions between tip and specimen from pure geometrical interactions. We have also developed a polished platinum sample for tip modeling verification work.

We will determine the tip processing, cleaning and deoxidization techniques which allow transfer of well-characterized tips to other measurement facilities and determine the stability of the probe tips in the uncontrolled environment. The longer-term technical strategy is the development of in-situ stabilized, atomically ordered surfaces which can be transferred to other measurement instruments such as M^3 or SEMs. This work builds on the current efforts for the development and characterization of nanometer scale standard artifacts such as atomically ordered surfaces and linewidth samples.

Prior Year Accomplishments

- High resolution charge coupled (CCD) frame grabber system has been installed to capture field in microscope (FIM) images which may then be transferred to analysis facility.
- Long range step and terrace structures have been fabricated with some local atomic order.
- Performed a preliminary study of contamination on systematically prepared tips as well as look at prolonged exposure in the UHV environment.
- Determined that single crystal irridium is not a good candidate for a tip material if FIM is the primary imaging tool.
- Moved the UHV preparation laboratory to the low vibration, actively sampled slab. Enhanced UHV frame structure and installed loadlock.
- Successfully investigated other candidate surfaces for tip analysis such as platinum.
- Participated in the NAMT effort using remote interactions and demonstrations of results obtained from the STM tip preparation and characterization project.
- Completed the construction of the FIFEM in the UHV STM. Develop useful methods of tip fabrication by field evaporation.
- SEM facility used to enhance the tip characterization effort.

- Developed consistent methods for the reproducible manufacturing of tip geometries, both in-situ and ex-situ.

FY 1998 Plans

- Install two-dimensional stage motion capabilities in the UHV STM.
- Develop oxidation methods for samples that have been measured atomically so as to stabilize the surfaces for measurements in other systems.
- Use the data exchange capabilities from the FIM and STM image acquisition systems and the computer modeling facility. Combine the experimental results with the modeling results and publish these results.
- Publish results on sample preparation and use of the atomically ordered samples.
- Measure atomically resolvable structures relevant to industry with well characterized tips.
- Use the UHV Prep Chamber for preparation of long range atomically ordered silicon surfaces. Prepare atomically ordered surfaces using etched features.
- Determine effects of atmospheric exposure on clean tips and the steps required for tip transportation.
- Use input from our SEM facility to enhance the tip characterization effort.

Five Year Plan Goals vs. Fiscal Year

1998 Develop techniques for controllable in-situ field evaporation and ambient etching SPM tip preparation.

1998 Implement modeling techniques which use the FIFEM results to give direct geometrical characterization of SPM tips.

1999 Develop modeling techniques which yield bounds on tip sizes directly from imaging and compare these results to geometrical sizes determined from FIFEM and SEM.

1999 Prepare atomic artifacts, consistent with other PED nanoscale projects, for tip characterization. Develop the techniques necessary to stabilize these canonically ordered, UHV prepared surfaces so they can be transferred to other measurement facilities (M-cubed, SEM, CAFM, etc.)

2001 Investigate and develop new techniques for tip characterization and fabrication as they become available.

1999 Advance SEM measurement capabilities in coordination with TEM and FIFEM to give accurate characterization of SPM tip properties.

2002 Design and certify standards for tip characterization based on the results of the preceding experiments and simulations.

2002 Measure nanometer-scale, topographically defined features with tips which have been well characterized, and obtain dimensionally accurate measurements of the features.

Standards & Measurement Services

Testing:

Industrial prepared wafer samples (Si 100) from industry partners are being prepared in the NIST UHV STM to have atomically order surfaces. This new method will provide critical dimensional measurements whose length scale is based on the intrinsic crystal lattice spacing.

Surface Finish Metrology

Leader: Vorburger, Theodore V.

Staff: Foreman, Charles
Renegar, Thomas Brian
Song, Junfeng

Total FTE: 2.60

1998 MEL Goals Supported

1. Laboratory research and development
2. Physical-based National and International Systems of Standards and Measurements

Project Objective

To develop and maintain the measurement systems and physical standards that underpin industry's measurements of surface finish and step height, to support industry's efforts to develop national and international documentary standards in this area, and to lead worldwide standardization efforts in selected sub-areas.

Needs Addressed

The surface finish affects the function of a wide range of industrial products. In particular, the surface finish affects the operation of components in the $170 billion auto industry (U.S.) and the $93 billion aerospace industry (U.S.), as well as other mechanical systems. It figures in the manufacture of $85 billion worth of integrated circuits (worldwide) and it affects the function of several billion dollars of optical components. The surfaces of these products must be specified and measured for surface finish. Since the surface finish topography of nearly all industrial parts is highly complex, the measurement of surface finish relies on detailed measurements of surface peaks and valleys and statistical algorithms and sampling procedures to characterize them. NIST calibrations and measurement research are critical to maintaining an accurate national measurement system for surface finish as are NIST contributions to standardization efforts to derive mutually agreeable and meaningful measurement results. An important part of this system is accurate calibration of critical surface features including step height for the semiconductor industry.

Technical Approach

We primarily use stylus-type profiling instruments to perform calibrations of standards and tests of industrial components. These profiling instruments are calibrated with master artifacts calibrated by optical interferometry. As an example of our capabilities, the 2 standard deviation uncertainty for our step height calibration is as small as ±0.3nm depending on the step height being calibrated. Using new techniques we are continuously upgrading either the hardware or software of these instruments or the calibration of our master artifacts or producing new standard reference materials (SRMs). We do these things to improve the accuracy, automation, and flexibility of our instruments and to meet new customer requirements. During FY 98, our emphasis will be on several types of standard reference materials for surface quality. We will also actively participate in the new International Organization for Standardization (ISO)Technical Committee (TC) 213 on Dimensional and Geometrical Product Specifications and Verification.

Prior Year Accomplishments

- Completed research on the effect of defocus on interferometric measurements of step height.
- Improved the turn around time of surface finish and step height calibrations to one month plus one week.
- Completed the machining of prototype random roughness specimens with high surface uniformity.
- Completed purchase of diamond turned sinusoidal roughness specimens with roughness average of 0.3µm for use as SRM2071b.

FY 1998 Plans

- Develop manufacturing plan for prototype standard reference materials for crime labs.
- Submit white paper on three-dimensional surface finish measurements to the ISO TC213 Advisory Group on the subject.
- Complete measurements of diamond machined random surface roughness specimens and formulate specifications for SRM prototypes.
- Submit research article on the effect of defocus on interferometric step height measurements to Precision Engineering or an equivalent journal.
- Improve the turnaround time of surface finish and step height calibrations to one month.
- Publish review article entitled "Characterization of Surface Topography".

Five Year Plan Goals vs. Fiscal Year

1999 Complete the integration of a y-axis table into the calibrated system for surface roughness measurement

1999 Install high speed gaussian filter software on the surface roughness calibration system

1999 Complete the development of control charts for both surface roughness and surface step height calibrations

2002 Maintain active participation in American Society of Mechanical Engineers (ASME) Committee B46, ASME H213, and ISO TC 213

2002 Continuously improve the accuracy of the existing surface finish and step height calibration service

Standards & Measurement Services

SRMs:

- Existing: SRM 2071-2075 - a series of five models of sinusoidal roughness specimens
- Researching: random surface precision roughness SRM, SRM for bullets and casings for crime labs.

Calibrations:

- Existing calibration service for roughness and step height.

Testing:

- Existing service for special roughness tests.

Committees:

ASME B46 on the Classification and Designation of Surface Qualities, ASME H213 and ISO TC 213 on Dimensional and Geometrical Product Specifications.

Ultraviolet Microscope

Leader: Potzick, James E.

Staff: Kornegay, Edward A.
Silver, Richard M.

Total FTE: .80

1998 MEL Goals Supported

1. Laboratory research and development.
2. Physical-based National and International Systems of Standards and Measurements.

Project Objective

To complete construction and qualification of the NIST Scanning Ultraviolet (UV) microscope.

Needs Addressed

As the United States' national standards laboratory, NIST provides Standard Reference Materials (SRMs) to meet industry calibration and traceability needs. The UV Microscope will be used to calibrate the NIST Photomask Linewidth SRMs and SRM 2800.

NIST Photomask Linewidth SRMs are the only traceable linewidth standards issued by NIST at this time. They are used worldwide to calibrate photomask metrology tools and by the scanning probe microscope community.

The new SRM 2800, Microscope Magnification Standard, will meet the dimensional traceability needs of many microscope users.

Technical Approach

The present green light calibration system is incapable of meeting these needs. The UV microscope is intended to replace that system. Some of the features of the UV instrument are: operation in UV, as well as visible light, to improve smallest measurable linewidth to 0.25 µm; structural design based on a Stewart platform for improved stability and lower vibration; use of a commercial computer-controlled DC motor/leadscrew scanning stage and z-axis coarse focusing actuators for less vibration, improved stage motion control, longer scan range, more accurate feature positioning, and wider focus range; inclusion of a UV charge injection device camera image monitor; and replacement of the (former) slit aperture with a pinhole sampling aperture for raster scanning (instead of 1-dimension scanning).

Reduce calibration uncertainty by measuring at UV wavelengths where chrome is less transparent (and where the photomask will be used), and by reducing vibration. In addition, the longer scan range will be used for calibrating the Optical Microscope Magnification Standard (new SRM 2800). The pinhole raster scan will allow measuring tilt (with respect to measurement axis), taper, and curvature of photomask lines.

A successor to SRM 473 Photomask Linewidth Standard is planned, extending the linewidth range to 0.25 µm. There has been discussion of 1:1 steppers at 248 nm or 193 nm illumination, where this linewidth range will be needed, and all of our customers queried have indicated a desire for 0.25 µm standard.

Extend the project to allow acquisition of through-focus aerial image data for comparison with modeling results.

Prior Year Accomplishments

- Computer program development has begun.
- The basic structure and illumination optics have been completed. The imaging optics and alignment are nearly completed.
- The focus and scan actuators have been upgraded to 0.1 µm resolution.
- Flow charts for the complex computer control and data acquisition program have been prepared.

FY 1998 Plans

- Compare linewidth measurements on new and old systems; estimate uncertainty.
- Write specific computer programs for calibration of linewidth and magnification SRMs.
- Write general computer programs for instrument control and data acquisition.

Five Year Plan Goals vs. Fiscal Year

1999 Develop and execute a plan for making the transition from calibrating photomasks on the green light system to the UV Microscope.

1999 Obtain data necessary to characterize performance of microscope and estimate uncertainty.

2002 Calibrate the new SRM 2800, Optical Microscope Magnification Standard.

Standards & Measurement Services

SRMs:

- SRM 2800 - Microscope Magnification Standard. This SRM is intended to be used for the calibration of reticles for optical or other microscopes at the user's desired magnification. It contains a pitch pattern consisting of a single array of lines with spacings ranging from 1 µm to 1 cm. This line scale is located in the center of a quartz microscope slide and consists of a lithographically produced chrome pattern. The SRM may be used in either the transmission or reflection mode. Calibration is traceable to the meter through NIST Line Scale Interferometer. (Under development; not yet available)
- SRM 473 - Photomask Linewidth Standard. This SRM was developed for use in calibrating optical microscopes used to measure linewidths on photomasks. Linewidth uncertainties are about 50 nm and pitch uncertainties are about 10 nm.
- Antireflecting chrome on quartz, 5 x 5 x 0.09 inches (127 x 127 x 2.3 mm). Certified line- and space-widths from 0.5 µm to 30 um. Pitch patterns: 30 lines with 1 um line/space, others to 70 µm. Price approximately $8000 each. (Currently out of stock)
- SRM 2059 - Photomask Linewidth Standard. This is a new SRM currently under development intended to replace SRM 473. Its design calls for linewidths and spacewidths from 0.25 µm to 32 µm and pitch patterns from 0.5 µm to 250 µm. It will be printed on a 6 x 6 x 0.25 inch quartz photomask substrate. (Not yet available)

Committees:

SEMI Microlithography Standards Committee

Nanomanufacturing of Atom-Based Standards

Principle Investigator:
Theodore V. Vorburger
(301) 975-3493
theodore.vorburger@nist.gov

Project Objective

To support the development and deployment of the technology of: (1) fabrication and use of nanometer-scale dimensional artifacts at geographically-distributed sites; (2) computer modeling, simulation, and prototyping of mechanical systems and components, including an artifact transport system for transporting critical artifacts between two or more sites in a highly-controlled environment; (3) remote telerobotic operation of scanned probe microscopes; and (4) links between sites by advanced computers and communications for high-speed video, voice, and data transmission among collaborating institutions in industry, government, and academia.

Needs Addressed

According to industry trends projected in the Semiconductor Industry Association's National Technology roadmap, within a decade, the critical dimensions of microelectronic devices will be near 100 nanometers, requiring dimensional standards with uncertainties near one nanometer and a degree of geometric perfection near to that of an ideal atomic lattice. As a result, NIST is undertaking development of atom-based dimensional standards, where feature size and geometry derive directly from that of the atomic lattice. Some of these physical standards will need to be fabricated, transported, and used at different sites, and spend their lives under vacuum or other highly-controlled environments. Microelectronic devices themselves may have a similar production cycle wherein expensive specialized equipment carry out different steps of the overall manufacturing process at different manufacturing sites. Such manufacturing steps include research and development, design, fabrication, inspection, processing, or repair. Many of these steps strongly depend upon sophisticated computer modeling, communications, and control.

Technical Approach

The project aims to: (1) demonstrate the feasibility of fabricating calibration standards with nanometer-scale dimensions for step-height, linewidth, and grid geometry where the size and geometry of the features is determined by atomic dimensions and crystal lattice properties; (2) develop a standardized, portable, artifact transport system to allow physical transport under vacuum of wafers and other substrates undergoing processing in high-vacuum systems in clean-room facilities at geographically-different locations; (3) demonstrate remote diagnostic operation of scanned probe microscopes using standard data representations and controller interfaces.

Editor's Note: This is a NAMT project. A detailed description of all NAMT projects appears within the Office of Manufacturing Program's section. This project appears here because it directly ties into this division's core mission.

Manufacturing Engineering Laboratory

Automated Production Technology

Acceleration and Shock Metrology

Leader: Eitzen, Donald G.

Staff: Evans, David J.
Payne, Beverly F.
Shoemaker Jr., Charles O.

Total FTE: 2.80

1998 MEL Goals, Supported

1. Laboratory research and development
2. Physical-based National and International Systems of Standards and Measurements

Project Objective

To provide U.S. industry with the best possible measurement services in dynamic-motion (vibration) metrology that industry needs and demands, and to remain the recognized top of the traceability chain in sinusoidal and transient acceleration. To assist in applying this measurement capability to solve manufacturing needs such as accurate, fast, actuator design. To provide special measurement expertise required by industry such as the evaluation of micromachined accelerometers. To assist U.S. sensor manufacturers to build sensor test platforms for product development. To improve the realization and delivery of services for acceleration measurement. To harmonize national and international standards on accelerometer calibration and vibration measurement.

Needs Addressed

Through its physical measurement services, special measurements, consulting, and standards work, this project impacts a very broad spectrum of manufacturing and production industries. Vibration measurements are used for environmental testing, diagnostics, product development, condition monitoring, process control, servo sensors, and global positioning. Some of the economic impacts involve products produced at very high volumes. In the auto industry, which is but one example of a segment relying heavily on acceleration measurements, many tens of staff years are spent measuring accelerations on vehicles for air bag deployment systems, and for ride control for a specific vehicle class. Delivery of systems in vehicles is measured in millions of units. Competitiveness and quality are obvious goals addressed by the project.

Technical Approach

The center of the approach is to maintain and improve significantly the accuracy and range of accelerometer measurement services, to continue our national and international standards committee work, and to undertake selected industrial measurement projects and Department of Defense (DoD) support when focused directly on our needs. For example the Supershaker work is largely funded by the Air Force Calibration Coordination Group (CCG) and is designed to provide us (and the Air Force) with a new generation of shakers for improved accelerometer calibration. One of the technical challenges in improving accelerometer calibrations is to develop a pure mechanical acceleration; acceleration that is sensibly zero in all but one direction, is purely sinusoidal at a single frequency but adjustable over many orders in frequency and several orders in magnitude. The shakers currently used to try to generate these motions were designed several decades ago and need to be modernized. Another challenge is the accurate measurement of mounting element motion. Special interferometry will be the principle tool for determination of actual element motion and for servo inputs.

Prior Year Accomplishments

- Completed paper documenting 30 years of calibration development.
- Performed calibrations and special tests as needed by industry, government and academia.

- Planned an international accelerometer intercomparison involving Canada, Mexico, Brazil, Argentina and the US in which NIST will serve as the pilot laboratory.
- Served as the chair of American National Standards Institute/Acoustical Society of America S2 Committee on Vibration and Shock.

Completed informal accelerometer calibration intercomparison with the German national measurement laboratory.

FY 1998 Plans

- Continue to improve the performance of the super shaker.
- Complete draft international standards on shock and vibration.
- Announce and begin new vibration calibration service with better than 1/2 % accuracy at selected frequencies.
- Perform calibrations and special tests as needed by industry, government and academia.
- Pilot intercomparison of accelerometer calibration with the 5 national laboratories of North and South American.

Five Year Plan Goals vs. Fiscal Year

1998 Complete upgrade of accelerometer calibration for the 20 kHz to 40 kHz range.

2000 Pilot, analyze data and report on the accelerometer calibration intercomparison among the Americas national laboratories.

2002 Perform calibration and special tests as needed by industry, academia and government.

2002 Improve uncertainty of vibration calibration.

2002 Complete upgrade of accelerometer calibration for the 3 Hz to 1 kHz range

Standards & Measurement Services

Calibrations:

Accelerometer calibrations and special tests.

Testing:

Provide special shock and vibration tests as required by industry, academia and government.

Committees:

ANSI S2 on Mechanical Vibration and shock; ISO TC 108 – Mechanical Vibration and Shock.

Acoustical Metrology Services

Leader: Nedzelnitsky, Victor

Staff: Eitzen, Donald G.
Evans, David J.
Wagner, Randall P.

Total FTE: 1.70

1998 MEL Goals Supported

1. Laboratory research and development
2. Physical-based National and International Systems of Standards and Measurements

Project Objective

To provide U.S. industry with the best possible measurement services for acoustical devices that industry needs and demands. To remain the recognized top of the traceability chain in free-field and pressure calibration of microphones. To provide special measurement expertise required by industry in developing revolutionary new sensors such as micro-machined silicon microphones and adaptive arrays of microphones. To improve the realization and delivery of calibration services for acoustical quantities. To harmonize national and international standards on acoustical instrumentation and microphone calibration. To represent the U.S. in international interlaboratory comparisons of primary calibrations of Laboratory Standard Microphones.

Needs Addressed

Through its physical measurement services, special measurements, consulting, and standards work this acoustic metrology project impacts a broad spectrum of U.S. industries and concerns such as acoustic measurements for noise control and abatement, safety and health programs, product development acceptance testing, condition monitoring, and object detection. Needs for measurements of electromagnetic interference effects on acoustical instrumentation are quickly escalating. Some of the economic impacts are very large. Acoustic measurements of new jet engine noise levels can have multi billion dollar impacts on engine and airframe manufacturers and on airline companies. Acoustic measurements in product development in the auto industry are extensive. National goals in health and safety are also very strongly affected.

Technical Approach

The center of the approach is to maintain and improve significantly the range of acoustical calibrations, to continue the extensive national and international standards committee work, and to develop critical and special measurements for revolutionary sensor technologies. Benchmarking our measurement services against other National Measurement Laboratories is a part of the approach. Modernization and complete characterization of equipment is essential, as is development of new measurement algorithms and signal processing techniques.

Prior Year Accomplishments

- Supported international trade by participating in an international intercomparison of microphone calibration among the national laboratories of North and South Americas.
- Completed paper on microphone acoustic center correction.
- Performed special measurements for Sony of America on a new advanced loudspeaker system.
- Completed recalibration of NIST microphones by primary (absolute) reciprocity.
- Provided technical support in the development of acoustical national standards by the American National Standards Institute/Acoustical Society of America Standards Committees S1 (Acoustics) and S3 (Bioacoustics).
- Provided microphone calibrations to industry and government as needed.

FY 1998 Plans

- Perform special acoustical tests for the Army.
- Provide leadership on the development of national and international standards.
- Perform microphone calibrations and special acoustic tests as required by industry, academia and government.
- Continue participation in the international comparison of microphone calibrations among the national laboratories in North and South Americas.

Five Year Plan Goals vs. Fiscal Year

1999 Complete international comparison of microphone calibration among the national laboratories of North and South Americas.

2000 Complete the development of acoustic calibration service so as to double the current frequency range.

2001 In support of the sensor industry, develop and perform special tests for revolutionary sensors as needed.

2002 Perform microphone calibrations and acoustical tests as required by industry, academia and government.

2002 Provide leadership in the development of national and international standards.

Standards & Measurement Services

Calibrations:

Perform microphone calibrations and special acoustical tests as needed by industry, academia and government.

Testing:

Develop and perform special acoustical tests in support of industry developments of advanced acoustical systems.

Committees:

- American National Standards Institute (ANSI) S1 (Acoustics) and S3 (Bioacoustics) committees
- Institute of Electronic and Electrical Engineers (IEEE) Electromagnetic Compatibility Society
- Acoustical Society of America (ASA) Committee on Standards
- International Electrotechnical Commission (IEC) TC 29 Electroacoustics
- U.S. Committee of IEC (USNC/IEC): service and technical advisor for IEC TC 29 Electroacoustics

Artifact Mass to Watt Competence

Leader: Jabbour, Zeina J.

Staff: Eitzen, Donald G.
Keller, Jerry G.
Lee, Vincent J.

Total FTE: 1.95

1998 MEL Goals Supported

1. Laboratory research and development.

Project Objective

To develop the research competence needed to accommodate, transition, and interface between the artifact mass system and future prescription based on physical constants such as is embodied by in the Electronics and Electrical Engineering Laboratory (EEEL) Watt experiment. The objective of the combined effort of EEEL's Watt experiment and this Automated Production Technology Division (APTD) project is to monitor the stability of Platinum-Iridium artifacts and eventually replace the mass artifact system, the last remaining fundamental unit defined by an artifact, with a prescriptional system based on physical constants.

Needs Addressed

The mass unit is fundamental to a broad range of manufacturing and producing industries. Some of the obvious segments include drug manufacturers, instrument manufacturers, and state weights and measures laboratories. Further, the mass unit is fundamental to the definition derived for both mechanical and electrical metrology. This leads to a potential impact to clientele spanning virtually all manufacturing and technical communities. The unit of mass is the last remaining fundamental unit defined by an artifact. The artifact is also, at the highest levels, unstable in the time frame of months and years due to ad- or absorbed material and in the time frame of decades due to not-understood mechanisms. The economic impact is obviously enormous and also includes such issues as engineering metrology, material accountability, equity in trade, and medicine and health. The fundamental issues are national and international.

Technical Approach

The technical strategy is to form a small team with competence in analytical physics, design of experiments, and experimental physics. The first task will be to transfer the detailed analytical and experimental knowledge base in mass measurements, corrections, and realization of the unit; particularly the knowledge base resident (a short time into the future) at NIST and the International Bureau of Weights and Measures, BIPM. One key technical issue to be addressed is the larger correction for air buoyancy resulting from the new unit definition due to the fact that the Watt experiment generates a volumeless force that is compared to an artifact with significant volume. This correction is approximately 100 mg for 1 kg and the residual uncertainty is troublesome. This uncertainty requires that our present capability in the measurement of the density of solid objects and the density of air be significantly improved. This effort requires the use of a controlled pressure chamber for the kilogram comparator so that constant, accurate, selected environments can be used. It also requires the design and use of air buoyancy artifacts that will result in a direct measurement of air density. Another required improvement to the dissemination system needed to tie the new and artifact systems together is a dedicated system to measure the (weak) magnetic susceptibility of kilogram standards and an improved system for determining the density of the kilogram standard. An improved understanding of artifact surface phenomena is also required. The other major element of this project is direct support of the Watt experiment itself. This includes newly designed artifacts for the experiment and input to the design of a new Watt balance.

Prior Year Accomplishments

- Completed clean room facility for kg research.
- Completed design of new solid density measurement system in cooperation with BIPM.
- Provided artifact and mechanical support to EEEL's Watt Experiement.
- Consulted with BIPM on density measurements.
- Presented research plans to NIST and MEL management

FY 1998 Plans

- Design temperature probe array for monitoring the kg comparator.
- Provide artifact and mechanical support to EEEL's Watt experiment.
- Complete design of artifacts required to study surface effects in controlled environment of the mass comparator.
- Complete plans for modifying comparator/enclosure for vacuum docking.

Five Year Plan Goals vs. Fiscal Year

1998 Complete apparatus for improved measurement of 1 kg mass standards.

1999 Complete methodology and devices for direct measurement of air density for mass correction.

1999 Complete system for studying material properties of artifact.

2000 Modify comparator/enclosure for vacuum docking.

2002 Close loop on US mass prototype K20 and Watt to within 10 parts per billion.

2002 Complete studies of kg mass standard stability under vacuum and controlled atmosphere.

Closed-Loop Manufacturing

Leader: Donmez, Alkan M.

Staff: Bandy, Herbert
Gilsinn, David E.
Hahn, Mahn Hee
Ling, Alice V.
Soons, Johannes A.
Welsch, Lawrence A.
Wilkin, Neil D.

Total FTE: 3.20

1998 MEL Goals Supported

1. Laboratory research and development.

Project Objective

To foster the development and implementation of advanced manufacturing systems, processes, and equipment through the development of the basic infrastructural tools needed to control manufacturing processes. To improve the accuracy of manufactured parts. To reduce lead-time to allow for the production of quality products in a cost-effective and flexible manner.

Needs Addressed

This project supports a broad spectrum of manufacturing industries, including the machine tool, aerospace, automotive and electronics industries. To compete effectively in global markets, U.S. industry needs to manufacture high-precision products reliably, predictably, in a timely manner at competitive costs. This requires a high degree of control over manufacturing processes, including the machines, tooling, and the inspection systems used in manufacturing. A total control strategy necessitates the characterization of all the elements involved in manufacturing processes. This characterization is time-consuming and can involve a few months to a year depending upon the machine features and the level of precision required. Machining processes and equipment, therefore, need to be understood better and all the factors influencing the precision of the manufactured product have to be taken into account.

Technical Approach

In collaboration with U.S. industry and the Advanced Technology Program, ATP, the closed-loop manufacturing project addresses various components of the precision machining processes and concentrates on development of the methods required to characterize manufacturing equipment, including machine tools, and their interactions with workpieces. These are being investigated as follows: (1) To insure that the Automated Production Technology Division, APTD, addresses the most urgent needs of industry, a series of industrial workshops are being sponsored. Findings from these workshops are utilized to direct and refine the project long-term plan. (2) To improve manufacturing processes, pre-, intermittent-, and post-process, sensor-based, control techniques and software algorithms are being developed that incorporate geometrical, thermal and dynamic tool, error compensation techniques. (3) To allow for timely sensory feedback, on-machine part inspection and analysis techniques are being developed using the results of the Machine Tool Characterization project.

Related Developments

- This project is closely related to Machine Tool Performance Characterization project as well as the Spindle Characterization project. The knowledge obtained from both of these projects is heavily utilized to accomplish the goals of the project described herein.

Prior Year Accomplishments

- Developed generic process-intermittent control algorithms capable of analyzing any part geometry using B-spline fitting and generating compensation during finish cuts.

- Developed high-speed data acquisition system based on National Instruments LabView which includes signal processing utilities such as Fast Fourier Transform (FFT), power spectrum, and histogram functions to be used for machining diagnostics.
- Two different motion control boards, one based on a Digital Signal Processor (DSP) chip and the other based on a microprocessor, were evaluated for their servo loop closure rate, dynamic resolution, and servo control algorithm accuracy.
- In collaboration with the Fabrication Technology Division (FTD), procured and developed a high-speed machining testbed and characterized its performance.
- Procured a laser interferometer based ball bar system for use in developing fast characterization methods for machine tools. Two machining centers have been measured using this new system.
- Provided support to manufacturing industry through participation in the development of national and international standards related to machine tool performance evaluation. Served as the Secretariat for ISO TC39/SC2 – Test Conditions for Machine Tools. Developed 24 draft international standards related to various types of machine tools in the last year.

FY 1998 Plans

- Develop plans to improve the post-process control strategies developed earlier for turned parts.
- Develop a methodology for propagation of machine performance uncertainties to predict the final uncertainties machined part geometry.
- Develop algorithms using clustering, trend and deviation analyses to determine conditions in which the actual machine performance deviates from the expected performance.
- Demonstrate the generic process-intermittent control algorithm on turned parts.
- Upgrade Quality Controller hardware platform.

Five Year Plan Goals vs. Fiscal Year

1998 Develop process control identification and control algorithms using advanced computational tools.

1998 Demonstrate the generic process-intermittent control algorithm on turned parts

1999 Extend closed-loop machining techniques and algorithms to cylindrical grinding for use in the automotive industry

2001 Investigate use of advanced sensors in machining applications

2000 Implement improved post-process control algorithms on turned parts

2001 Investigate process control needs and requirements for precision forming processes

Standards & Measurement Services

Committees:

- Served as the Secretariat for ISO TC39/SC2 – Test Conditions for Machine Tools.
- Developed 24 draft international standards related to various types of machine tools in the last year.

Detection and Control of Subsurface Damage for Single Crystal Optics

Leader: Polvani, Robert S.

Staff: Evans, Christopher J.

Total FTE: .30

1998 MEL Goals Supported

1. Laboratory research and development.

Project Objective

Develop effective, nondestructive testing for detecting and controlling subsurface damage in high performance single crystal components. Preferably, do this in-process as part of manufacturing metrology. Three examples of emerging commercial applications are: calcium fluoride in 193 nm ultra-violet steppers and sapphire windows in seeker missiles or deep ultra-violet steppers and silicon for soft x-ray project lithography.

Primarily, we address APTD's traditional role of providing new means for and support for manufacturing metrology. We are also in a partnership with Ceramics Division (MSEL) and Precision Engineering Division (MEL), allowing each to make a best effort - people, skills and hardware. MEL has a long standing commitment to fabrication technology and metrology of high performance optics, MSEL has made outstanding contributions to understanding the physical nature of ceramic materials. This task needs many skills to succeed.

Needs Addressed

No standards or generally-agreed-upon measurement methods exist for sub-surface damage control, yet, control of subsurface damage (SSD) is a key to reducing fabrication costs. Because we now lack reliable means to measure SSD, inordinate fabrication times and care are substituted. The hazard of SSD is real. Damage incurred early in manufacturing precision components can be covered over in later stages. Although components appear fully functional, they are in fact badly impaired. This is true for glass, metal and ceramic parts, and is a hazard to their mechanical strength and optical performance. We are trying to define the physical nature of SSD first, and to find better ways of performing in-process metrology.

Technical Approach

A typical optical material, sapphire, is a hard, brittle, non-conductor. Because of its varied physical attributes, sapphire is an ideal vehicle material for studying SSD. It has the transparency of glass and uses the same fabrication processes. Unlike glass, sapphire, along with metals and other ceramics, deforms plastically. Because it readily transmits ultraviolet through infrared wavelengths, a variety of optical examination methods can be employed. These can range from simple optical microscopy to Raman Spectroscopy and trace-impurity based photoluminesce. In unstressed stock, the refractive index is constant along the optical axis, but stressed sapphire is highly birefringent. Long range order - a single crystal - means the full family of diffraction methods electrons, neutron and x-ray - are available for damage imaging.

Prior Year Accomplishments

- CONSULTING: Supported Sapphire Statistical Characterization and Risk Reduction (SSCARR) Program as needed.
- DIAGNOSTICS: Characterized available SSCARR coupons, developing coordinated diagnostics inspection methodology, and X-ray topography completed on 90 correlation coupons.
- STRENGTHENED SAPPHIRE: Characterized SSCARR coupons for strengthening effects from annealing, stress coating and "other" ideas.

- MICRO-RAMAN SPECTROSCOPY: Examined crystallography and beam polarization effects on Raman peak shifts.
- STANDARDS: Two zero, c-axis SSD Standard prototypes are in use. X-ray used to define SSD bounds from lapping.
- SHOP FLOOR INSPECTIONS: Examined seven Theater High Altitude Area Defense (THAAD) missile windows for wind tunnel test effects.

FY 1998 Plans

- CONSULTING: Support SSCARR as needed.
- SHOP FLOOR INSPECTIONS: Use surface finish, light scattering, wave front analysis and PLM with SSD prototype standards.
- STANDARDS: Issue a-axis and c-axis zero SSD Standards. Characterize sawing, lapping, grinding and polishing damages. Fabricate lapped SSD artifacts.
- MICRO-RAMAN SPECTROSCOPY: Replace scalar stress with a tensor representation. Correlate Raman to x-ray and optical measurements of SSCARR coupons.
- STRENGTHED SAPPHIRE: Use X-rays, Transimission Electron Microscopy (TEM) and Polarized Light Microscopy (PLM) to define effects of annealing, trace addition and "other" processing. Evaluate effect on emissivity.
- DIAGNOSTICS: Issue final report, use additional coupons and a refined methodology to correlate "lethal" defect with strength.

Five Year Plan Goals vs. Fiscal Year

1998 Provide consulting

1998 Issue report for Diagnostics for Assuring Reliability

1999 Develop Raman Spectroscopy Metrology

2000 Investigate possibility of "Strengthened" Sapphire

2001 Demonstrate means for effective shop floor inspections of sapphire components

2001 Fabricate sets of sub-surface damage standards for industrial use.

Figure and Finish Metrology for Advanced Optics

Leader: Evans, Christopher J.

Staff: Dixson, Ronald G.
McGlauflin, Michael L.
Parks, Robert E.
Vorburger, Theodore V.

Total FTE: .85

1998 MEL Goals Supported

1. Laboratory research and development
2. Physical-based National and International Systems of Standards and Measurements

Project Objective

In optical fabrication improvements in manufacturing methods and in metrology go hand in hand. The objective of this project, which compliments the Wafer Flatness and Precision Machining of Advanced Materials projects, is to develop, in cooperation with the Precision Engineering Division, traceable measurement techniques to measure deviations from the ideal form of advanced optics. These include aspherics, such as to be used in extreme UV lithography (EUVL), as well as components for programs such as the National Ignition Facility (NIF) and the Laser Interferometric Gravity-wave Observatory (LIGO). For EUVL optics departures from the ideal form with spatial wavelengths ranging from a fraction of the x-ray wavelength (13 nm) to the full aperture of the part (300 mm) must be measured. In that range, figure error, comprised of the long spatial wavelength deviations, causes degradation of the image quality. The surface finish, comprised of the short spatial wavelengths, causes diffusely scattered light and degradation of contrast.

Needs Addressed

Improved measurement methods are required to support trade in high precision optical components that are crucial to many advanced products. The continuing drive for ever smaller integrated circuit feature sizes means that the fundamental physical limits of lithography using transmissive optics and near visible illumination will be exceeded early in the next decade. EUVL is one attractive replacement technology and one in which the U.S. currently has a technological lead; feature sizes below 100 nm have been produced by EUVL over small field sizes in laboratory systems. Economic production, however, will require large field sizes and good optical efficiency, in turn requiring extremely accurate optical elements with superb surface finish. Companies attempting to make these optics do not have the measurement capabilities they need, and they cannot make what they cannot measure. These optics may be the heart of the next generation of lithography systems, themselves the machine tools of the silicon industry. That industry is worth $85 billion per year. Similar needs, at the limits of optical fabrication technology and of measurement methods, are found in both science and commerce.

Technical Approach

NIST work has shown that atomic force microscopes (AFMs) and visible phase measuring interferometers (PMIs) have the necessary resolution for finish and figure measurement, respectively. Commercially available instruments, as supplied, are insufficiently accurate. NIST has developed a calibrated AFM that can establish the traceability of optical surface finish measurements. The instrument has on-line calibration in the X and Y directions using laser interferometry that will ultimately be accurate to ±3 nm. A capacitance gauge will provide calibration in the Z-direction of ±0.1 nm, which, in turn, is calibrated off-line using laser interferometry.

Commercially available PMIs can be extremely repeatable and have been shown to be adequate for projects such as LIGO.

However, they do not currently have the absolute accuracy needed for aspherics. Concepts for a system combining a PMI with high precision slideways have been developed and, over the next three years, will be implemented (in collaboration with an industrial vendor) in a new measurement capability, known as the NIST X-ray Optics Calibration Interferometer (XCALIBIR). The goal is less than 1nm peak-to-valley uncertainty in measurement of aspheric optics up to 300 mm diameter with focal lengths up to 2 m. We also need to be able to measure flat and spherical wavefronts to similar accuracies — capabilities that are included in the new system's design.

Related Developments

- A new interferometer concept developed at Lawrence Livermore offers an alternative measurement approach for some optics, possibly at lower cost than systems such as XCALIBIR. Intercomparisons between measurements will provide increased confidence in the measurement infrastructure. Techniques to evaluate sub-surface damage in advanced crystalline optics have been developed at NIST; they will be applied as needed to lithography optics.

Prior Year Accomplishments

- Published papers/made presentations to international optics and lithography communities.
- Measured coated and uncoated development optics for LIGO
- Measured coated spherical optics for EUVL system

FY 1998 Plans

- Evaluate NIST participation in NASA large optics calibration project.
- Complete research on surface tilt effects in phase measuring micro-interferometers.
- Install XCALIBIR
- Support development of in-house metrology for LIGO
- Measure LIGO observatory optics as requested.

Five Year Plan Goals vs. Fiscal Year

1999 Develop uncertainty budget for finish metrology.

1999 Complete LIGO metrology.

1999 Commission XCALIBIR

2000 Develop aspheric test methods on XCALIBIR

2000 Install XCALIBIR

2001 Develop uncertainty budget for asphere testing

2001 Start XCALIBIR calibration service

2002 Introduce asphere calibration service

Standards & Measurement Services

Committees:

ISO TC 172- optics and optical instruments

Force Metrology

Leader: Yaniv, Simone L.

Staff: Bartel, Thomas W.
Chesnutwood, Kevin L.
Ho, Samuel L.
Seifarth, Ricky L.

Total FTE: 4.50

1998 MEL Goals Supported

1. Laboratory research and development
2. Physical-based National and International Systems of Standards and Measurements
5. Customer satisfaction and program recognition

Project Objective

To provide U.S. industry with the high-accuracy force measurement services it needs to remain competitive in world markets. To provide industry with access to the top of the traceability chain in the US force measurement system. To provide leadership in force standards developments. To provide leadership in assuring compatibility between international and national standards. To serve, in the force area, as the technical arm of the National Conference of Weight and Measures. To improve the delivery of force measurement services to industry. To help US industry meet the requirements set forth by legal metrology organizations. To perform the intercomparisons required to remove trade barriers with our global partners.

Needs Addressed

Accurate force measurements are critical to commerce, manufacturing and research. Force measurements are essential in determining such things as the power developed by the internal combustion engine and the strengh of materials, components, and structures such as bridges, buildings, vessels, and tanks. Force measurement applications include weighing commodities, weighing vehicles, tanks, bins, conveyor systems, monorail weighing and other weighing applications. Also, automated industrial processors such as rolling mills require accurate force measurement to control roll pressure on bar steel, sheet metal, paper etc. Measurement of thrust of engine on rocket test stands, torque on dynamometer stands, cable tension on winches and elevators, as well as structure-checking for weight, lift, balance and drag are but a few examples of the many applications which depend upon accurate force measurements. Accordingly, through its force measurement services, special tests, research, consulting and standards work, the project supports the broadest possible spectrum of manufacturing industries, including aerospace, aircraft, automotive, nuclear, defense, chemical, electrical, materials, and other industries, academia and government. The project provides to US industry a means to assure traceability to national and international standards, and contributes to quality and safety in manufacturing. Through this project, NIST also provides to US industry the means required to ensure that their products meet legal metrology requirements at both the national and international levels, and the data required for mutual recognition agreements among global trading partners.

Technical Approach

To achieve its goals, the force group will continue to maintain a world class facility that includes the primary national force standards over a range of 0.5 kN to 4.4 MN, and to modernize and upgrade the delivery of its services as required. In addition, it maintains a hydraulic testing machine capable of generating forces up to 53 MN for calibrating large capacity force transducers through comparison with secondary force transfer standards. Moreover, since force transducers are used in environments that differ widely, from the tropic to the arctic, the force group will continue to provide testing for and to research the effects of environmental factors on the performance of force transducers. In addition, the group will continue to work with national and international standards groups to insure that barriers to world markets are minimized for US manufacturers. To that end, the group will continue to benchmark its capabilities against the national laboratories of other nations, perform calibrations and special tests, monitor developments that will require new measurement capabilities, conduct research to improve measurement uncertainties or to resolve outstanding standards issues, and serve as the technical arm of the National Conference of Weights and Measures, NCWM.

Related Developments

- The International Bureau of Weights and Measures, BIPM, and the Directors of the national metrology institutes of the nations that signed the “Convention du Metre” are negotiating an agreement for mutual recognition of national standards and calibration certificates issued by these institutes. Mutual recognition would be based upon key intercomparisons carried out under the auspices of the Consultative Committees of BIPM. When the agreement is concluded, the project will provide the means for NIST to implement its obligation under this agreement in the force area.

Prior Year Accomplishments

- Made significant progress on the implementation of the Manufacturing Engineering Laboratory, MEL, Quality Manual/ISO Guide 25 in the force laboratories.
- Reported on force metrology capabilities at NIST to the 1997 National Conference of Standards Laboratories; and documented these capabilities in the conference proceedings.
- Negotiated with several countries the terms for an international intercomparison of a standard developed by the Organization for Legal Metrology (OIML) OIML R-60. The force group will serve as the pilot laboratory for the US, Australia, Germany, England and Canada while Australia will serve as the pilot laboratory for the Asian Pacific ream countries and the US.
- Provided technical support for the development of force and related standards to American Society for Testing and Material, ASTM E3 Committee and served as a technical expert on the US Technical Advisory Group for OIML TC 9.
- Continued support of load cell manufacturers by performing OIML and National Type Evaluation Program (NTEP) tests.
- Maintained and disseminated the unit of force by providing calibration services to industry, government and academia, and documented over 2500 test results.
- Completed research on load cell creep and creep recovery, and documented results in archival publication.

FY 1998 Plans

- Complete experimental phase of comparability of results obtained with alternating current (AC) and direct current (DC) excitation voltage of load cells.
- Begin to serve as the pilot laboratory for a three years OIML R-60 intercomparison involving Canada, Australia, England, Germany and the US.
- Provide consultations to industry, academia and government as needed.
- Complete implementation of MEL Quality manual in the force group
- Refurbish the 25000 lbf deadweight machine
- Support load cell manufacturers by providing NTEP and OIML tests.
- Continue work on national and international standards; strive to achieve harmonization between national and international standards.
- Perform force calibrations and special tests for industry, government and academia as needed.
- Begin serving as the pilot laboratory for a three-years, OIML R 60 intercomparison involving the National laboratories of Germany, England, Canada, Russia, Australia and the US.

Five Year Plan Goals vs. Fiscal Year

1998 Complete implementation of MEL quality manual/ISO Guide 25

1998 Refurbish the 5620.2 N (25000 lbf) deadweight machine.

1999 Report on comparability of data obtained with AC and DC excitation voltage of load cells.

2000 Serve as pilot laboratory for an OIML R-60 international intercomparison

2002 Actively participate in national and international standardization efforts.

2002 Provide consultations to Industry, academia and government as needed.

2002 Support load cell manufacturers by providing OIML/NTEP tests as needed.

2002 Perform force calibrations and special tests on behalf of industry, government and academia as needed.

2002 Refurbish the 67442.7 N (300000 lbf) deadweight machine

2002 Refurbish the 224808.9 N (1000000 lbf) deadweight machine.

Standards & Measurement Services

Calibrations:

Perform force calibrations and special tests.

Testing:

Support load cell manufacturers by providing OIML/NTEP tests

Committees:

- ASTM E28-Mechanical testing;
- NCWM National Conference on Weights and Measures - Serve as technical arm
- US TAG OIML TC 9 Weighting Sector Committee - Serve as technical expert;
- Member of BIPM Consultive Committee on Mass and Related Quanntities

Hearing Aid Metrology

Leader: Wagner, Randall P.

Staff: Burnett, Edwin D.
Eitzen, Donald G.
Nedzelnitsky, Victor

Total FTE: 2.05

1998 MEL Goals Supported

1. Laboratory research and development
2. Physical-based National and International Systems of Standards and Measurements

Project Objective

To provide the Department of Veterans Affairs (VA), and the public, with evaluated data on hearing aids so that a rational match can be made between patient needs and available aids. To develop test methodologies, often extremely software-intensive, necessary to test ever-more complex and sophisticated hearing aids. To provide the necessary standards support for hearing aid manufacturers, prescribers, and users. To assist hearing aid manufacturers in the development of better aids. To communicate the results of these tests in a clear and open way. To provide acoustic and related technical support as needed by the VA and their suppliers.

Needs Addressed

Through special facilities and instrumentation, anthropomorphs, complex measurement algorithms, extensive software development, and sophisticated signal processing, this hearing aid metrology project fulfills the health, information and support needs of the VA and supports the industrial development of improved aids by manufacturers. It also provides the public with useful, needed, hearing aid information. The VA purchases a very large numberof hearing aids and the need for test results for a rational aid selection criteria (developed by VA) is great. The project results improve the quality of life of our war-injured veterans and of the hearing-impaired.

Technical Approach

The center of the approach is the development of special facilities, instrumentation, complex measurement algorithms, software, and signal processing to provide valid measurements on diverse and constantly changing linear and nonlinear hearing aid devices. The approach also includes standards support for hearing aid technology, consulting with manufacturers, and technical support for the VA on measurement protocols and support for equipment purchases, e.g., audiology booths.

Prior Year Accomplishments

- Provided support to hearing aid manufacturers and standardization bodies.
- Completed technical report for VA on new procedures and data analysis methods.
- Provided extensive consultations to VA on acoustical measurements methodologies for hearing aids.
- Tested several dozen new in-the-ear (ITE) custom hearing aids.
- Completed development of new software intensive data reduction and analysis procedures for the data gathered on custom hearing aids.
- Measured characteristics of programmable directional ITE and behind-the-ear (BTE) hearing aids.

FY 1998 Plans

- Provide support to hearing aid manufacturers.
- Provide leadership in the development of hearing aid standards.
- Test hearing aids on behalf of VA.
- Complete technical report for VA on test procedures and analysis used forhearing aids to be tested this year on behalf of VA..

Five Year Plan Goals vs. Fiscal Year

2002 Develop new test procedures for the evaluation of new generation of hearing aids as needed by the VA.

2002 Complete reports to the VA on applicable test procedures and data analysis methods.

2002 Continue to provide leadership on national and international standards for hearing aids.

2002 Provide support to hearing aid manufacturers as needed.

Standards & Measurement Services

Testing:

Perform hearing aid testing on behalf of the VA.

Committees:

- ANSI S3 WG48 on Hearing Aids
- ANSI S3 WG80 on probe microphone measurement in real ears.
- USNC/IEC representationin IEC TC 29 Electroacoustics including hearing aids.

High Speed Machining

Leader: Davies, Matthew A.

Staff: Damazo, Bradley
Dutterer, Brian
Gilsinn, David E
Kennedy, Michael
Soons, Johannes A.

Total FTE: 1.35

1998 MEL Goals Supported

1. Laboratory research and development

Project Objective

To work with US industry on increasing the accuracy and productivity of high-speed machining through the development of measurement, modeling and control methodologies necessary to optimize the process.

Needs Addressed

High-speed machining allows increased production rates, for a given quality or improvement in surface quality. It also provides economic alternative manufacturing strategies, and hence its industrial use is rapidly increasing. Over the past ten years the speed of commercial machining centers has increased by nearly an order of magnitude (e.g. 40000 rpm, 30 kW spindles and machine slide speeds of up to 60 m/min), and this technology is finding a wide range of applications in many industries. However, because of their complexity, optimization of these processes is difficult and often counterintuitive. The goal of this work is to aid US industry by developing measurement and modeling methodologies aimed at increasing accuracy and productivity of high-speed machining processes with a wide range of tool and workpiece materials and configurations.

Technical Approach

NIST is developing a high-speed, milling testbed around a recently-installed the Makino A55 high-speed machining center. This testbed is a joint effort between APTD and FTD in which the machine functions both as a research tool and as a producer of reimbursable components for NIST researchers. To meet the research needs, APTD is installing state-of-the-art equipment capable of measuring the most important aspects of the high-speed milling process including (1) cutting forces; (2) tool dynamics and vibration; and (3) material flow in the formation of chips. Several focus areas of the research are being developed: (1) measurement and enhancement of the dynamic stability of tools; (2) predictive models of tool dynamics and cutting forces; (3) determination of the various factors affecting tool wear in high-speed milling of advanced materials and (4) collaborative efforts with machine-tool characterization researchers to measure and predict sources of errors in high-speed contouring operations. Driven partially by internal NIST machining requests submitted to FTD, a research effort is also being initiated in micro-mechanical machining processes.

Prior Year Accomplishments

- Submitted two journal articles for publication.
- Investigated the feasibility of mounting a low-power, 60000 rpm auxiliary spindle on the Makino to expand the micromachining capabilities of the machine.
- Brian Dutterer of the Fabrication Technology Division, FTD, completed 50-60 machining assignments for NIST personnel as part of this collaborative effort with the Automated Production Technology Division. The machining of several of these components required us to test the micromachining capabilities of the Makino Mill.

- Tuned a 11.8 mm diameter, 118 mm long tool for dynamic stability in cutting at 20,000 rpm. Produced an example part with 102 mm deep pockets to demonstrate the utility of this tool.
- Compared cutting test results with theoretical predictions of tool stability made using data from impulse response tests. Verified the validity of the models.
- Devised methods of characterizing the impulse response of high length-to-diameter ratio endmills
- Tested the stability of several high length-to-diameter ratio endmills provided by Boeing
- Designed, constructed, and tested capacitance probes for measuring dynamic tool deflections during machining.
- Established an interface between the machine and the computer for communication using Virtual Gibbs and MasterCam software. Components for FTD were made within three weeks of installing the machine.
- Purchased, installed, tested and accepted a Makino A55, High-speed Milling center.
- Initiated a project with Boeing in St. Louis to dynamically tune high-length-to-diameter endmills for high-speed machining of aluminum components.
- Investigated and purchased standardized hollow shank, HSK, tooling for the machine. HSK is the new standard tooling for high-speed machining.

FY 1998 Plans

- Implement a novel control scheme to limit once per revolution vibrations on a high-speed grinding machine.
- Develop models to explain the observed experimental results, and expand our understanding and predictive capability in high-speed machining.
- Utilize the capacitance probe fixture to further investigate the stability behavior of long endmills particularly focusing on cornering and plunge cuts.
- Investigate the use of active fixturing to increase the stability of high-speed machining.
- Design and test several concepts for passive tool damping techniques and variable pitch cutters aimed at increasing the vibrational stability of long endmills. Evaluate and report the results in a technical publication.
- Using the open architecture features of the Fanuc-16 controller, establish communication between the Makino and a digital signal processor, DSP, board installed in a personal computer (PC). This is a fundamental step in establishing more flexible experimental capability on the high-speed machine.

Five Year Plan Goals vs. Fiscal Year

1999 Develop competence in the prediction and practical utilization of stability in high-speed machining.

2000 Work with industry and academia to disseminate knowledge useful for increasing the accuracy and material removal rates in high-speed machining.

2000 Develop systems for accurate measurement and monitoring of high-speed machining process variables.

2000 Pursue efforts in high-speed micro-mechanical machining with the possibility of developing a new separate project in the future.

2002 Obtain and conduct machining tests with state-of-the-art high-speed machining equipment. Continue joint-efforts with FTD.

Machine Tool Characterization

Leader: Soons, Johannes A.

Staff: Damazo, Bradley
Davies, Matthew A.
Donmez, M Alkan
Gilsinn, David E.
Harper, Kari K.
Kennedy, Michael

Total FTE: 1.75

1998 MEL Goals Supported

1. Laboratory research and development
2. Physical-based National and International Systems of Standards and Measurements

Project Objective

To provide U.S. industry with the parameters, test methods, models, and data analysis tools necessary to assess, describe, and improve the performance of machine tools used for material removal. To provide leadership in the development of machine tool performance evaluation standards, including harmonization between national and international standards. The project focuses on machine tool characteristics that determine the accuracy of machined parts.

Needs Addressed

Machine tool manufacturers and users require procedures to characterize machine tool performance for the following reasons: 1) to specify the mutual obligations, deliverables, and methods of verification between machine tool users and sellers, 2) to compare the performance of machines, 3) to estimate and ensure the tolerances of parts produced, and 4) to obtain the data required to monitor, diagnose, and improve machine tool performance. Machine tool characterization is difficult because there are many geometrical, thermal, and dynamic sources of error whose effects on part accuracy are complex. Current test methods are elaborate. The resulting performance parameters are difficult to translate into part tolerances obtained under real cutting conditions. The situation is further complicated by the lack of harmonization in both the terminology and data analysis tools used in various national and international standards. Many standards do not reflect the state-off-the-art in machine tool characterization. The Association for Manufacturing Technology, AMT, Technology Roadmap for the Machine Tool Industry targets a 70% improvement of machine tool accuracy between 1995 and 2005. Improved performance evaluation and error compensation techniques will play a critical role in reaching that goal.

Technical Approach

In collaboration with U.S. industry, the machine tool characterization project addresses the development of methods to characterize machine tools and their interactions with work pieces, and provides leadership in national and international standardization efforts. Research areas include (1) development of faster, more practical machine tool characterization procedures that yield meaningful error parameters (2) development of methods to translate machine tool performance parameters into part tolerances, (3) development of models for geometric, thermal, and dynamic machine tool errors, (4) development of robust compensation methods for geometric and thermal errors, (5) study of new machine types, including parallel machines such as hexapods and high-speed milling machines (6) development of measurement procedures to ensure that performance parameters reflect machine tool accuracy under cutting conditions.

Related Developments

- This project is closely related to and provides input to the close-loop manufacturing project and several National Advanced Manufacturing Testbed, NAMT, projects.

Prior Year Accomplishments

- Developed first prototype of a data dictionary to efficiently communicate and store the conditions, setup, and measurement results of performance evaluations.
- Developed techniques for uncertainty analysis and error budgeting of hexapod machine tools.
- Developed and tested several techniques to assess, model, and compensate the geometric and thermal errors of a hexapod machine tool.
- Developed virtual machining software for the hexapod.
- Started characterization of the high-speed machining testbed.
- Procured a laser interferometer based ball bar system for use in developing fast characterization methods for machine tools.
- Received IR100 award for Machining Variation Analysis, a method to predict and diagnose the tolerances of machined parts (with the Massachusetts Institute of Technology, MIT, and the Landis division of Western Atlas).
- Provided support to U.S. manufacturing industry by active participation in national and international standards organizations. Served as the Secretariat for ISO TC39/SC2 - Test Conditions for Machine Tools. Developed 24 draft international standards related to various types of machine tools.

FY 1998 Plans

- Develop more efficient techniques to assess the geometric errors of hexapod machine tools.
- Begin characterization, modeling and improvement of the dynamic properties of a hexapod machine tool.
- Begin investigation into performance evaluation tests of rotary axes, including fast tests to assess the axes of rotation.
- Continue work on the data dictionary.
- Begin investigation into a methodology for the propagation of machine performance uncertainties to predict the final uncertainties in machined part geometry.
- Begin investigation into the distribution, correlation, and properties of typical machine tool errors.
- Begin investigation into the measurement of parametric errors during continuous motion as opposed to sampling at stationary points.
- Begin characterization of dynamic contouring errors at high speeds.
- Complete guide on parametric error models for machine tools including a library of kinematic models for the most common machine tool configurations.
- Complete characterization of high-speed machining testbed.
- Continue support of U.S. manufacturing industry by providing leadership in National and International standards organizations.

Five Year Plan Goals vs. Fiscal Year

1999 Complete investigation into performance evaluation tests of rotary axes, including fast tests to assess the axes of rotation.

1999 Study contouring errors at high speeds.

2000 Develop a methodology for the propagation of machine performance uncertainties to predict the final uncertainties in machined part geometry.

2000 Develop methods for characterizing, modeling, and improving the dynamic errors of hexapod machine tools.

2000 Study Distribution, correlation, and properties of typical machine tool errors.

2000 Characterize shops CNC machine tools.

2000 Develop virtual machine tool for the hexapod..

2002 Continue support of the data dictionary

2002 Continue support of U.S. manufacturing industry by providing leadership in National and International standards organizations

2001 Develop performance evaluation tests and related standards for grinding machines

2001 Develop methods to characterize machine tools under loaded conditions

2002 Develop Performance evaluation tests and related standards for rapid prototyping

Standards & Measurement Services

Committee:

- American Society of Mechanical Engineers (ASME) B5/TC52 - Technical Committee for Developing Performance Standards for Machining Center and Turning Center Standards
- Electronic Industries Association (EIA) IE 31 - Numerical Control;
- International Organization for Standardization (ISO) IS) TC39/SC2- Test conditions for machine tools. Served as secretariat.

Mass Artifact Metrology

Leader: Jabbour, Zeina J.

Staff: Crupe, William E.
Eitzen, Donald G.
Keller, Jerry G.
Martinez, Linda

Total FTE: 3.40

1998 MEL Goals Supported

1. Laboratory research and development
2. Physical-based National and International Systems of Standards and Measurements
5. Customer satisfaction and program recognition

Project Objective

To provide U.S. industry with the highest-accuracy services in mass metrology that industry needs and demands. To remain the recognized top of the traceability chain in mass. To assist in the realization of derived units such as force and pressure. To provide special measurement services required by industry such as solid density measurements. To assure the compatibility of U.S. mass measurement with those of other nations and of international standards with those of the United States. To improve the realization and delivery of mass measurement services and to conduct the applied research necessary to achieve these services.

Needs Addressed

The mass unit is fundamental to a broad range of manufacturing industries and to commerce. Some of the obvious segments include drug manufacturers, instrument manufacturers, power companies, and state weights and measures laboratories. Further, the mass unit is fundamental to the definition of derived units in both mechanical and electrical metrology. This leads to a potential impact to clientele spanning virtually all manufacturing and technical communities. The economic impact is obviously enormous and also includes such issues as engineering metrology, nuclear material accountability, equity in trade, safety, medicine and health. The fundamental issues are national and international.

Technical Approach

The essential technical approach is to maintain and improve a core competence in the realization and dissemination of the unit of mass, in the measurement of density (solid, liquid, and air) and in the measurements leading to the realization of derived units such as force and pressure. In addition, considerable effort must be performed with exacting accuracy and great care, and the entire chain of realization of the unit, and of the check and working standards, must be maintained. This includes international benchmarking of our mass artifacts. The publication of papers on mass metrology is an important part of this strategy.

Prior Year Accomplishments

- Jointly designed with the International Bureau of Weights and Measures, BIPM, an upgraded solid density measurement system.
- Completed the NIST portion of an international comparison sponsored by BIPM of the 1 kg stainless steel standards.
- Continued to upgrade the mass calibration services in the range of 2 kg to 10 kg.
- Provided leadership in national and international standardization work.
- Maintained and disseminated through calibration services the unit of mass to industry and to state weights and measures laboratories.
- Completed new clean room mass laboratory.
- Completed paper describing mass metrology at NIST.

FY 1998 Plans

- Implement MEL Quality Manual in the mass laboratory.
- Complete upgrade of mass calibration services in the range of 2 kg to 10 kg.
- Begin construction of new solid density measurement system based on the BIPM/NIST design.
- Participate in BIPM key international comparisons.
- Provide leadership in national and international standardization work.
- Maintain and disseminate the unit of mass to industry, academia and government.

Five Year Plan Goals vs. Fiscal Year

1999 Develop improved measurement service for weights in the 100 g to 1 kg range.

2000 Develop improved measurement service for weights in the 1 mg to 100 g range.

2002 Provide leadership in national and international standardization work.

2002 Maintain and disseminate the unit of mass to industry and States Weights and Measures laboratories.

2000 Develop improved measurement service for weights in the 1 kg to 20 kg range

Standards & Measurement Services

Calibrations:

Provide mass calibrations

Committees:

- ASTM E41.06 Weighing Devices
- General Conference of Weights and Measures (CGPM) Consultative Committee on Mass and related quantities
- Organization Internationale de Metrologie Legale (OIML) SC3 TC 9 Instruments for measuring mass and density.

Precision Machining of Advanced Materials

Leader: Evans, Christopher J.

Staff: Chou, Kevin
Davies, Matthew A.
Hwang, Tae Wook
McGlauflin, Michael L.
Polvani, Robert S.
Whitenton, Eric P.

Total FTE: 3.10

1998 MEL Goals Supported

1. Laboratory research and development

Project Objective

In cooperation with the Material Science and Engineering Laboratory, MSEL, to develop manufacturing methods—including metrology and sensor feedback to open architecture controllers—to allow cost-effective production of tight tolerance components in advanced, difficult-to-machine materials such as ceramics, crystals, and hardened steels. Applications include mechanical, optical and electronic systems ranging from bearings and turbine blades to space optics and magnetic memories.

Needs Addressed

There is an increasing trend to both tighter manufacturing tolerances and higher performance materials. For example, next generation turbine blades will be made from silicon nitride, and require complex, accurate forms with good surface finish and no machining-induced, strengt-limiting, defects. Machining costs are currently a high proportion of the total manufacturing cost, and must be reduced if advanced materials are to be cost competitive. At the same time, defect density and surface finish must be controlled. Complex interactions between machine characteristics, tool and work materials, and process parameters must be understood as they provide the technological basis for manufacturing processes that will allow introduction of new products based on such materials. Improved grinding techniques will enhance the manufacturability of high-value-added, tight tolerance components. Potential industries impacted include aerospace, transportation, and mass storage.

Technical Approach

The project aims to improve the-state-of-the-art in ductile regime grinding and hard turning. Brittle materials behave in an apparently ductile manner under certain process conditions, allowing defect free ceramic surfaces to be diamond ground with small uncut chip thickness achieved by using fine grit wheels. Rapid wheel wear, however, means that continuous electrochemical dressing is required of the metal bond wheels; fundamental understanding of the dressing process, and its integration and control via an open architecture controller are required. Appropriate instrumentation will be developed to give sensory feedback for real-time control of the grinding process as well. Higher wheel speed can also reduce per grit removal, improving part quality without increasing manufacturing time. Wheel wear and machine dynamic performances become critical issues. Loop stiffness and damping appear to have an impact on tool wear as well as surface integrity in hard turning; the new tools of non-linear dynamic analysis are being applied to understanding these effects. Chemical and microstructural effects in the wear of cubic boron nitride, CBN, and other tool materials wear need to be better understood.

Related Developments

• High speed grinding research and development is receiving major attention in Germany and Japan, with some interest in the US at the University of Connecticut and the University of Massachusetts . Through participation in the "College International Pour l'Etude Scientifique des

Techniques de Production Mecanique," CIRP, collaborative efforts, we are leveraging our resources in this area, and applying the knowledge base from hard metal grinding to ceramics machining.

Prior Year Accomplishments

- Evaluated white layer formation mechanism and process effects on white layer depth in hard turning.
- Completed preliminary study of surface speed effects in silicon nitride grinding.
- Compared chip formation in hard steels with amorphous nickel.
- Demonstrated effect of tool and work piece microstructure on CBN tool wear in finish hard turning.
- Developed model of chip formation.

FY 1998 Plans

- Investigate microstructural evolution during white layer formation in hard turning.
- Install kinematic wheel mount in high-speed grinder.
- Install powered dresser with integral acoustic emission sensors in high-speed grinder.
- Investigate tool wear in interrupted cutting with CBN tools.
- Investigate feasibility of single crystal sapphire tools.

Five Year Plan Goals vs. Fiscal Year

1998 Develop basic electrochemical theory for dressing process.

1999 Perform sensor evaluation for grinding control.

1999 Establish bench-top techniques for evaluating potential new coolants for electromechanically assisted in process dressing.

1999 Evaluate single crystal sapphire tools

1999 Evaluate plated wheel wear in silicon nitride grinding.

2002 Develop process-based sensory feedback to grinding machine controller.

Standards & Measurement Services

Testing:

On-machine sensor systems

Committees:

ISO TC 213 WG 3 - Dimensional and Geometrical Product Specifications and Verification committee, Reference temperature working group.

Process Modeling

Leader: Davies, Matthew A.

Staff: Chou, Kevin
Evans, Christopher J.
Gilsinn, David E.
Polvani, Robert S.
Pratt, John R.

Total FTE: 2.20

1998 MEL Goals Supported

1. Laboratory research and development

Project Objective

To develop and test physically-based models of manufacturing processes that can act as the foundation for both improved process planning and for new process development. To develop measurement methods for key materials properties.

Needs Addressed

Enterprise-level models of manufacturing help improve competitiveness of US companies. The most basic element of these models is the model of the material removal process. Current models of material removal processes are generally poor at predicting performance. Although they are reasonably effective at interpolating within the bounds of experimentally obtained machinability data. The cost of obtaining such data, however, is high -particularly as it is required for every alloy and every process. Effective process planning and enterprise modeling are seen as critical elements to improved manufacturing flexibility and productivity; poor process models may limit the advantage gained.

Technical Approach

The approach taken in the project is based on the development of models of material removal processes based on the complex thermo-mechanical interactions between tool and workpiece. Initially, models will be developed for a range of processes that are significant economically and tend to be dominated by specific, individual aspects of the problem that are amenable to experimental validation. For example, the project includes development of a moving heat-source model to predict trends in white layer formation in finish hard turning and a thermo-plastic model to predict transitions from continuous shear to segmented chip formation. These effects, and others, must be accounted for in any complete model. Note that initial developments of the models has indicated inadequacies in materials data, in the constitutive models available at appropriate (high) strain rates on materials of commercial interest and in phase transformations in steels under combined thermal and mechanical transients.

Other process models will be developed for aspects of high-speed grinding, lapping, and milling. In the milling of flexible, thin-walled components chatter prediction has been based on linear models and non-linearities due to intermittent engagement in partial immersion cuts have been ignored. Nonlinear models may capture much of this previously ignored behavior and point to previously-unknown higher productivity areas of stability in machining parameter process space.

As confidence grows in the individual aspects of material removal process modeling, they will be combined and integrated with aspects of machine performance models. In parallel, the project will drive work to develop appropriate materials property data as needed. Throughout, the project will be closely tied to other projects including precision machining of advanced materials, high speed machining, machine tool characterization, wafer flatness and micromachining etc. Similarly, the process models will indicate the characteristics of the process that, if sensors of the appropriate sensitivity and bandwidth are available, might be used in process control and monitoring.

Prior Year Accomplishments

- Instrumented high-speed machining center for experimental in-process measurement of vibration and cutting force.
- Developed and verified experimentally initial models of chip segmentation and white layer formation in hard turning.
- Evaluated frequency response of polyvinylidenefluoride (PVDF) process-monitor sensor.
- Began developing non-linear dynamic models for high-speed milling.
- Expanded non-linear model for milling thin-walled flexible parts to include changing surface characteristics and verified experimentally.

FY 1998 Plans

- Refine moving heat source model for white layer formation in hard turning.
- Develop model for wheel wear in high-speed ceramics grinding.
- Demonstrate application of milling tool dynamic model.
- Evaluate lapping model

Five Year Plan Goals vs. Fiscal Year

1999 Develop non-linear models for milling dynamics.

2001 Develop and test models for prediction of forces, temperatures and material flow patterns in high-speed machining.

Sensor Interfaces and Networking for Manufacturing

Leader: Lee, Kang

Staff: Gavin, Robert
Huff, Michael
Savoy, Toni
Schneeman, Richard D.

Total FTE: 5.00

1998 MEL Goals Supported

1. Laboratory research and development
2. Physical-based National and International Systems of Standards and Measurements

Project Objective

To provide leadership in standardization organizations to facilitate the development of smart transducer interfaces for sensors and actuators. To participate in the development of the sensor interface and sensor networking specifications and standards for measurement and control applications in manufacturing. To develop hardware and software for smart transducer interface reference implementations in collaboration with industry in order to assess and evaluate the operability and functionality of the standards. To work with industry to develop conformance testing specification and procedures for smart transducer (sensor and actuators) interfaces. To help US industry and other government agencies adopt and implement the sensor interface standards.

Needs Addressed

Sensors and actuators are used in a wide range of applications such as industrial automation, manufacturing process control, machinery monitoring and control, semiconductor devices manufacturing, and building automation. Typical sensors include devices and micro-electro-mechanical system (MEMS) that measure pressure, acceleration, flow, force, temperature, vibration, torque, and position, etc. The sensor and actuator business including MEMS is a multi-billion dollar enterprise in the United States. The world sensor market is expected to grow to $13 billion by the year 2000. With the emergence of smart sensors, digital communication, and networking technology, sensor companies are gradually applying these technologies into their devices. However, due to the lack of common interfaces for connecting sensors to microprocessors and field networks, it is prohibitedly costly for sensor producers to develop custom interfaces to support the multitude of networks and protocols in the market. Thus, sensor manufacturers are urgently seeking a standard interface for the sensors. Through this project, the resulting standardized sensor interfaces will not only solve the device compatibility problem, they will also minimize the economic risk in technology investment, accelerate the implementation of smart technology in sensors, provide the opportunity for achieving "plug and play" interoperability between sensors and networks, and provide the enabling technology for integration and networking of sensors and actuators into distributed measurement control systems for use in manufacturing.

Technical Approach

The Sensor Integration Group will take the following steps to fulfill the needs of industry. The Group will take a leadership role and participate in voluntary standardization organizations such as the Institute of Electrical and Electronics Engineering, (IEEE), and International Society for Measurement and Control, (ISA), to facilitate the development of standards for sensor communication interfaces and protocols, and the development of an information model for networked smart sensors and actuators. This includes sponsoring workshops for establishing industry priorities, facilitating and actively participating in working group meetings for a drafting specification for the standards. The Group, in collaboration with industry, will develop hardware and software reference implementations based on the draft specification to evaluate technical feasibility and compliance and to provide feedback to the standards committees. This includes dealing with technical issues such as digital communication protocols and timing for data and commands, transducer electronic data sheet (TEDS) for the self-describing of sensors to systems, hot swaps for the "plug and play" of sensors to field networks, minimization of the number of wires for the interfaces, and software interfaces for the network independent model to interact with smart sensors and Internet protocols such as Transmission Control Protocol/Internet Protocol (TCP/IP), User Datagram Protocol/Internet Protocol (UDP/IP), and open network protocol such as LonTalk. The Group will collaborate with industry group(s) to demonstrate the reference implementations in conferences and expositions. The Group will disseminate information of the standardization activities through meetings, publications, conference presentations, internet, and Websites to broaden industry awareness of the interface standards. The Group will participate as a consortium partner in the international Intelligent Manufacturing System (IMS)-Sensor Fused Intelligent Monitoring System for Machining (SIMON) project to further disseminate sensor interface information to the international community and establish collaboration in sensor-based machining and manufacturing projects.

Prior Year Accomplishments

- Demonstrated the remote access of sensor and actuator information through the use of Internet and Web technologies.
- Disseminated smart transducer interface technical information through conferences, publications, and meetings.
- Organized industry consortium group consisting of ten companies demonstrating commercially developed IEEE 1451.2-compatible transducers and other implementation of the interface specification at the Industry Standard Architecture (ISA) Tech/97.
- Collaborated with industry partners and directed staff members to develop and demonstrate reference implementation and to show application of the P1451 smart transducer interface draft standards.
- Coordinated with the P1451.1 working group to complete the first round of balloting on IEEE P1451.1 D1.83.
- Coordinated with two industry working groups to prepare final specifications for their respective draft standards P1451.1 and P1451.2
- Coordinated with the IEEE Standards Office to establish the IEEE 1451.2 as a full-use standards through the rigorous industry balloting process.
- Provided leadership to the IEEE Sensor Technology Committee - served as Chairman of the Committee and Member of the Administrative Committee of I&MS.
- Organized and submitted project authorization requests (PAR) to IEEE for P1451.3 and P1451.4 which resulted in the acceptance of the two as formal working groups with the purposes of developing the respective draft standards.
- Hosted second P1451.3 and P1451.4 study group meeting at NIST.
- Sponsored and chaired study group meeting for IEEE P1451.4, Digital Communication and Transducer Electronic Data Sheet (TEDS) Formats for Distributed Multidrop Systems.
- Sponsored and chaired study group meeting for IEEE P1451.3, Mixed-mode Communication Protocols and Transducer Electronic Data Sheet (TEDS) Formats.

FY 1998 Plans

- Participate in IMS-SIMON meetings for scientific information exchange and project collaboration.
- Coordinate efforts with the international Intelligent Manufacturing System(IMS) - Sensor Fused Intelligent Monitoring System for Machining (SIMON) project and work with the United States coordinator University of Michigan and NIST legal counsel to finalize the consortium cooperative agreement.
- Continue to develop sensor interface Website to link with IEEE, I&MS, MEL and other national organizations.
- Facilitate and participate in P1451.X working group meeting.
- Organize a public demonstration of smart transducer interface P1451.X.
- Collaborate with sensor manufacturers, users, and national lab to develop P1451.X-compatible devices and networking systems to evaluate standards compliance.
- Develop software and hardware to implement P1451.X draft specifications.
- Participate in the Networking, Industrial Communication, and Buses Theme Committee in planning the ISA Expo/98 to be held in Houston, TX.
- Continue to play a leadership role in the smart transducer interface standardization effort by chairing the TC9 Committee.

Five Year Plan Goals vs. Fiscal Year

2002 Participate in IMS-SIMON Project

2002 Provide technical support to sensor/actuator industry

2002 Develop interface standards for sensor and actuators.

2002 Develop hardware and software required to demonstrate sensor/actuator interface functionality.

Standards & Measurement Services

Committees:

IEEE Instrumentation and Measurement Society Technical Committee on Sensor Technology TC-9; IMS-SIMON WP6 ;IEEE P1451 (Standard for a Smart Tranducer Interface for Sensors & Actuators) P1451.1 Working Group; IEEE P1451.2 Working Group; IEEE P1451.3 Working Group; IEEE P1451.4 Working Group.

Spindle Characterization

Leader: Damazo, Bradley

Staff: Hahn, Mahn Hee
Harper, Kari K.

Total FTE: 1.20

1998 MEL Goals Supported

1. Laboratory research and development
2. Physical-based National and International Systems of Standards and Measurements

Project Objective

To develop the fundamental knowledge required to understand the relationship between measured spindle performance and manufactured part quality.

Needs Addressed

U.S. industry has an ever-increasing need to produce high precision parts to remain competitive in global markets. Because the majority of manufacturing processes utilize spindles, the accuracy of these components is crucial. In-depth study of the characteristics of a variety of spindle types and the relationship of those characteristics to performance in manufacturing is being done to assist industry in the development of more accurate spindles.

As industry continues to push the state-of-the-art of machining in an effort to remain competitive, there is a strong demand for ever-faster cutting speeds. High-speed machining can increase productivity, reduce waste, and improve surface finish quality. Thus industry is clamoring for higher-speed machining, and high-quality, high-speed spindles are at the heart high speed machining.

Technical Approach

A complete study of the geometric, thermal, and dynamic properties of a 8,000 rpm water hydrostatic spindle will be started. Analysis of the axis of rotation errors, thermal distortion, vibration modes, and non-linear dynamic effects will be carried out. Weldon Machine Tool, Inc., The Torrington Company, the University of Maryland, and the Massachusetts Institute of Technology are collaborating with APTD on this project. Methodologies for spindle analysis developed in this effort will be made available to industry through publications and presentations in relevant forums. Correlations found between spindle characteristics and performance will also be presented to industry for its use in development of more accurate spindles.

Industry has developed new miniature accelerometers based on the microelectromechanical systems technology (MEMS). Such accelerometers will be studied and characterized with the intent of embedding these accelerometers in spindles to measure and control ofundesired dynamics and to improve the spindles accuracy. The micromachining industry uses machine tools with very high spindle speeds to match the material removal rate of the small tools. A new research program will be developed to support this industry.

Other machine components such as controllers, drive systems, tool/spindle interfaces will be considered for investigation in the future stages of this project.

Prior Year Accomplishments

- Initiated talks with Torrington and Weldon concerning new 8,000 rpm hydrostatic spindle
- Designed fixturing system to adapt a 60,000 rpm spindle to the high speed machining center.
- Began characterizing the geometric, thermal and dynamic characteristics of a high-speed 20,000 rpm spindle.

- Developed data acquisition system and fixturing system for measuring dynamic response and axis rotation errors of end-mills in a high-speed machining center spindle for speeds up to 20,000 rpm.
- Measured the dynamic characteristics of the improved roller bearing spindle and compared to results obtained with the old system.
- Continued collaboration with industry to modify the existing axis of rotation standard. Participated in the American Society of Mechanical Engineers (ASME) B89.3.4-Axis of Rotation standards committee meeting to revise the existing Axis of Rotation standard.

FY 1998 Plans

- Develop testbed and test methods for measuring performance of MEMS fabricated micro accelerometers.
- Perform experimental micromachining cutting tests with 20,000 rpm and 60,000 rpm spindles on a high-speed machining center. Compare results.
- Initiate micromachining research program
- Manufacture and integrate a fixturing system to adapt a 60,000 rpm spindle to a high speed machining center.
- Continue characterization of geometric, thermal and dynamic characteristics of the hydrostatic spindle.
- Improve data acquisition system and required fixturing for measuring dynamic response and axis of rotation errors of end-mills in high speed machining center spindle for speed up to 20,000 rpm.
- Continue collaboration with industry to modify the existing axis of rotation standard. Attend standards committee meetings and assist with writing standards documents

Standards & Measurement Services

Committees:

ASME

Ultrasonic Calibration Services and Related Research

Leader: Fick, Steven E.

Staff: Blessing, Gerald V.
Slotwinski, John A.

Total FTE: 1.10

1998 MEL Goals Supported

1. Laboratory research and development
2. Physical-based National and International Systems of Standards and Measurements

Project Objective

To deliver ultrasonic calibrations, including ultrasonic reference block echo-amplitude measurements, transducer output power measurements, and sensitivity measurements of acoustic emission (AE) sensors as a function of elastic wave frequency. In addition, we respond to industrial requests for specific tests in a timely manner.

Needs Addressed

Ultrasonic calibrations address a variety of critical issues from the safety of bridges and aircraft, to the integrity of nuclear pressure vessels, to the health of the unborn fetus. The country's highway and airway infrastructures rely on the accuracy of inspection teams' nondestructive testing (NDT) instrumentation for the detection of possible failure mechanisms such as cracks. Ultrasonic inspection techniques represent a significant portion of in-field inspections, due in part to their low cost and instrumentation portability. Cracks in an aircraft's fuselage, its wingspan, and numerous other critical locations – especially, those emanating from fastener sites – must be detected for human safety. NIST's Ultrasonic Standards Group offers a calibration service, used by various industrial sectors such as aerospace and metals, of metal blocks possessing defect artifacts in a variety of sizes that may be used to set system instrumentation sensitivity.

The integrity of pressure vessels in the nuclear industry, giant storage vessels in the oil industry, etc. relies on periodic (sometimes constant) monitoring by acoustic emission (AE) methods. The detection need is for incipient cracks in metal containers, and delaminations and fiber-matrix separations in composite structures. The concept is that a growing crack releases a sudden burst of elastic wave energy, which may then be detected via well-positioned AE sensors. The calibration of the AE system may be accomplished by generating a source of wave energy – a breaking pencil lead e.g. – and observing whether the sensor system responds with its detection and associated algorithm for source location. The Ultrasonics Group develops repetitive and reliable sources of elastic wave energy, which simulate the signatures of growing cracks, and offers a unique primary calibration of the sensors themselves.

The medical diagnostic field requires accurate measurement methods for the power generated by its imaging (and other) instrumentation. This is especially recognized for the pre-natal scans – "sonograms" - that have become ubiquitous in the gynecology field. NIST offers a calibration of the output power generated by a transducer source which may then be used in a secondary calibration of the power levels generated by instrumentation residing in a hospital or doctor's office.

Technical Approach

In ultrasonic reference block echo-amplitude measurements, we deliver an evaluation of the echo-amplitude response from flat-bottom reference artifacts in metal blocks that industry uses to calibrate the sensitivity of its ultrasonic systems to detect material flaws. The principal users are the aerospace and metals industries, e.g., Boeing and Century Aluminum. In power radiation measurements of transducer output, NIST provides a measure of transducer power output radiation as a function of drive voltage so that the user may have a reference to calibrate the output levels of his system. A lithium-niobate piezoelectric source was developed as a well-characterized transducer transfer device to the medical community for evaluation of their diagnostic and therapeutic systems.

We offer a unique acoustic emission calibration for measuring the impulse-response of piezoelectric displacement sensors over a frequency range from 0.1 MHz to 1.0 MHz. The outputs of a capacitive absolute-displacementreference tranducer and the sensor being calibrated are compared to determine sensitivity to normal surface displacement due to the transient surface wave generated by a breaking glass capillary. The magnitude (in volts per μm) and phase of the transducer sensitivity are obtained at discrete frequencies over the above calibration range.

Prior Year Accomplishments

- Completed study to determine level of nonlinear wave propagation in industrial NDT systems.
- Compared the performance of ceramic and quartz transducers for reference block calibrations.
- Provided leadership to standards community and chaired the American Society for Testing and Materials (ASTM) committee on ultrasonic reference block.
- Calibrated ultrasonic power transfer standards. Calibrated metal-detect artifacts for the aerospace and metals industries.

FY 1998 Plans

- Finalize ISO documentation for the "secondary calibration of Acoustic Emission Transducers."
- Conduct statistical analyses of ultrasonic reference block calibration system performance
- Evaluate specific piezoelectric ceramics transducers as potential replacements for quartz standard source for the ASTM standard.
- Provided leadership to national and international standards groups.
- Provide calibrations to industry as needed.

Five Year Plan Goals vs. Fiscal Year

1999 Develop improved practices for reference block methodology.

1999 Continue to provide leadership to national and international standards groups.

1999 Provide calibrations to industry as needed.

Standards & Measurement Services

Calibrations:

Provide ultrasonic calibrations.

Testing:

Provide ultrasonic special tests as needed by industry.

Committees:

- ASTM E7 Nondestructive Testing
- ASTM E28 Mechanical Testing
- ASTM SC7.91 –U.S. Technical Advisory Group for International Standards Organization Technical Committee135 on Nondestructive Testing

Ultrasonic Quality Control for Industry

Leader: Blessing, Gerald V.

Staff: Fick, Steven E.
Hsu, Nelson N.
Slotwinski, John A.
Xiang, Dan

Total FTE: 1.90

1998 MEL Goals Supported

1. Laboratory research and development

Project Objective

Develop, test, and apply ultrasonic methods to industrial nondestructive testing and process control needs. The tasks may include sensor development, wave propagation studies in materials and structures, and data analysis.

Needs Addressed

Ultrasound provides a general, nondestructive, testing capability to inspect for material quality, for defects in manufactured parts, and for in-process monitoring for quality control. The technology is pervasive in many industrial sectors, especially the metals, automotive, and aerospace manufacturing industries. It also has application to existent major structures such as nuclear pressure vessels, large storage tanks, bridges, etc., where a failure of the unit may result in a major catastrophe.

Specific applications are for composites including layered materials that both the automotive and aerospace sectors are turning to for improved strength-to-weight ratio materials. New ceramic and ceramic-coated metals are also being developed requiring new, quality-control, technologies to assure their integrity in use. Their intrinsically heterogeneous structures make it difficult for the manufacturer to control uniformity of the products. As a result, industry often turns to nondestructive evaluation techniques for confirmation of product quality and uniformity. Off-the-shelf sensors and inspection systems often cannot meet its needs, leading to NIST's development of new hardware components (especially sensors) and methodologies.

Technical Approach

The Ultrasonics Group is working with other researchers for in-process sensing during cutting and grinding procedures. Novel, in-situ, sensor applications are being made to assess the variation in cutting forces that are operative during hard metal turning. The resulting ultrasonic signatures require careful analysis and correlation with machine processes. Efforts are being made to increase the signal-to-noise, and to distinguish machine background vibrations and electrical noise from the desired tool-workpiece interactions. It is a goal to apply a similar methodology to ceramic grinding where the material removal mechanism is, in general, quite distinct from that with metals. Ceramic grinding removes material by the brittle fracture of "chunks" or grains of the ceramic, while metal cutting involves the ductile flow of material. The in-situ detection of ceramic grinding processes will therefore attempt to sense microscopic fractures in order to monitor the process.

Related Developments

Industry's calibration needs are addressed in a separate project description. In support of its standardization requirements for defect artifacts and sensor evaluations, we calibrate ultrasonic blocks, transducers for medical diagnosis, and acoustic emission sensors used to monitor for incipient failure. We also serve on a number of ASTM standards committees and provide input to international standardization bodies.

FY 1998 Plans

- Assist industries, in particular those with whom we have a Cooperative Research and Development Agreement (CRADA), with consultations on their sensor requirements and acoustic signature analyses.
- Determine the elastic wave frequency content associated with specific cutting or grinding procedures in order to determine sensor bandwidth requirements.
- Evaluate certain piezoelectric sensors for their capability to monitor ceramic grinding processes.

Five Year Plan Goals vs. Fiscal Year

2000 Analyze ultrasonic signatures and correlate with on-line sensor needs of industry

2001 Evaluate and develop piezoelectric sensors for their sensitivity to machining processes

2001 Apply new sensor technologies to cutting and grinding operations for in-process monitoring applications

2002 Support industry through technical conferences and standards committees activities.

Standards & Measurement Services

Committees:

- ASTM E07.06.02 - Nondestructive Testing for Ultrasonic Reference Blocks
- ASTM E28.03 - Modulus Measurements
- ASTM E28.13 - Mechanical Measurements committee, Stress Measurements subcommittee
- ASTM SC7.91 - ISO Liaison to International Electrotechnical Commission (IEC); IEEE Ultrasonics Ferroelectrics & Frequency Control Administrative and Technical Program Committee

Ultrasonics Research & Development

Leader: Hsu, Nelson N.

Staff: Blessing, Gerald V.
Xiang, Dan

Total FTE: 1.70

1998 MEL Goals Supported

1. Laboratory research and development

Project Objective

Develop cost-effective and novel ultrasonic testing methods for measuring strength-related properties of advanced ceramic and composite materials. The methods rely on two key elements: new transducers that have been developed at NIST for ultrasonic measurements, and the theory of elastic wave propagation that has been formulated for such transducers. Further developments will involve the optimization of transducers, and application-specific theories.

Needs Addressed

Industrial sectors ranging from electronics to transportation are experiencing an increased reliance on more exacting and complex material structures for their products. For example, the electronics industry demands near-perfect quality for its single-crystal substrate material used in the manufacture of microchips. Other industries are developing large single grains for high performance engines. Material manufacturers are developing a variety of composite structures such as fiber-reinforced metals and nonmetals, ceramic and plastic-coated materials, and multi-layer laminates.

These new materials require the development of testing techniques for in-process control, and subsequently for in-service functionality and safety assurance. The attractiveness of ultrasonic techniques is not only due to their nondestructive character, but also to their capability for penetrating opaque solids to allow the measurement of intrinsic material properties and detection of defects. But these techniques, to be reliable, require both effective and well-characterized sensors, and an unambiguous interpretation of the test results.

Technical Approach

An approach is used based on the Group's expertise in the design and characterization of transducers, and in the analytical knowledge of both wave propagation and signal processing. The development of a line-focus, large-aperture, wideband, low cost transducer capable of generating and detecting short duration pulses to facilitate time domain operation is pursued.

The transducer, which has directional sensitivity, is used in a multi-axis (x, y, z, theta) scanning system for testing inhomogeneous and anisotropic material samples. We will develop theoretical models to predict the waveforms in layered anisotropic media, and use those same models to simulate the test results. We will further develop signal processing and graphic display techniques for easy interpretation.

The next step is to select sample materials of industrial importance, carry out tests and perform statistical analyses documenting the uncertainty, identifying the error sources, and making improvements in the testing methodology.

Journal publications and technical symposia will serve as useful mechanisms for both technology transfer and industry feedback. Our efforts will be leveraged through cooperation (informal and/or Cooperative Research and Development Agreement (CRADA)) with university, industrial and government laboratories.

Related Developments

- Acoustic-emission sensor characterization and calibration
- Design of ultrasonic transducers using piezoelectric polymers
- Ultrasonic techniques for probing liquid/solid interfaces
- Ultrasonic techniques probing the interface between welded and cemented solids
- The time-domain Green's function of layered solids

Prior Year Accomplishments

- Since 1995, we have designed, constructed and tested more than thirty large-aperture line-focus polymer film transducers. We have procured, modified and assembled two scanning systems, developed software for data acquisition and display, and developed theoretical simulations for several test configurations.
- Researchers from more than twenty organizations have visited our laboratories and seen demonstrations of our results. Many have requested the key part of the system - the transducer, and since 1995 we have loaned ten such units for test and evaluation.
- We have published twelve papers and made more than twenty presentations at national and international meetings. Steps have been taken for a U.S. patent "Time and Polarization Resolved Acoustic Microscope": disclosure - April 3, 1995; application - May 10, 1996; allowance - Oct. 9, 1997

FY 1998 Plans

- Develop new transducer application without requirement for sample immersion.
- Extend frequency range of transducers.
- Develop new software platforms for multi-dimensional data display.

Five Year Plan Goals vs. Fiscal Year

1998 Extend frequency range.

1999 Apply robust software display platforms for sensor data

2002 Technology transfer via university and industry interactions

2002 Present research to tech. conferences and journal public

2002 Develop novel transducer hybrids for industry's needs

Standards & Measurement Services

Committees:

ASTM E7 on Nondestructive testing; ASTM E28 on Mechanical Testing; IEEE Ultrasonics Ferroelectrics &Frequency Control Admin. and Tech. Program Committees.

Wafer Flatness

Leader: Evans, Christopher J.

Staff: McGlauflin, Michael L.
Parks, Robert E.
Whitenton, Eric P.

Total FTE: 1.20

1998 MEL Goals Supported

1. Laboratory research and development

Project Objective

The objective of the project is to develop metrology and manufacturing methods for the production of smooth substrates for very-large-scale integrated circuits and to allow optimization of in-process chemo-mechanical planarization. Continuously-decreasing, integrated circuit feature sizes force down the acceptable wafer surface defect size, while productivity concerns are driving up the substrate diameter. Decreasing feature size is also focusing attention on silicon-on-insulator substrates as an alternative to bulk silicon.

Needs Addressed

Wafers need to be locally flat—over at least the die site—in many Integrated Circuit (IC) production processes. In others, particularly chemo-mechanical planarization, productivity may be increased if wafers are globally flat. In all these processes, wafers are mounted on a variety of chucks that can affect local and global flatness. Traceable metrology for flatness over 300 mm apertures is not available and, according to SEMATECH, is seen by wafer vendors as a fundamental constraint to introduction of 300 mm wafers. In addition, improved methods are needed for measurement of local and global thickness variation. Improved metrology may lead to inherently flatter substrates which will be easier to planarize to the required defect levels as wafer size increases. Improved production methods are also needed to bring down the costs of silicon-on-insulator (SOI) substrates. Either silicon or SOI substrates will be the feedstock for the IC industry that is worth $85 billion per year.

Technical Approach

NIST work has shown that flatness measurements with uncertainties less than 5 nm can be made on 150 mm diameter substrates using current interferometers. Two routes will be taken to extend that performance: a modified Ritchey-Common configuration has been developed on the existing NIST 100 mm aperture interferometer to extend its range to 300 mm diameter, with some minor loss of accuracy. In parallel, a new 300mm aperture interferometer (XCALIBIR) with target uncertainties of the order of 1nm is being developed for a range of applications including flatness (see separate MEL 1998 Project Description “Figure and Finish Metrology for Advanced Optics”). These interferometers will be used to evaluate a variety of chucking concepts, including adaptive chucks. With increased wafer diameters, new techniques are needed for measurement of thickness variations; a novel IR interferometer has been demonstrated as a laboratory prototype and is being scaled up to 300 mm aperture.

Given appropriate metrology, increased productivity in both the production of substrates and the in-process planarization steps requires both incremental improvements of current processes and evaluation of novel procedures. New combinations of chemical and mechanical processes will be evaluated for silicon-on-sapphire substrate production. New lap concepts will be evaluated for substrate production and for in-process, chemo-mechanical polishing of oxide and metal layers. Application of the same lap technology to photomask blank polishing will be investigated.

Related Developments

- Substrates for semi-conductor application are a commodity where major process changes typically take place only with a new generation of product. The transition to 300 mm diameter wafers is driving such a period of change. Wafer thickness metrology has been dominated by capacitance gauging, and new instruments based on this method are being built. The IR interferometer is an alternate method. The new polishing methods are also timely as companies worldwide develop new systems for substrate production in in-process planarization.

Prior Year Accomplishments

- Demonstrated chemo-mechanical polishing of oxide, tungsten and copper using the Rapidly Renewable Lap.
- Implemented Ritchey-Common interferometer as a full phase shifting system at 300 mm aperture.

FY 1998 Plans

- Measure chucked 300 mm wafers using Ritchey-Common system
- Demonstrate photomask lapping methods.
- Begin Commissioning of XCALIBIR
- Install 300 mm aperture IR interferometer.

Five Year Plan Goals vs. Fiscal Year

1998 Evaluate photomask lapping methods

1998 Evaluate 300 mm chuck performance using R-C interferometer

1999 Scale-up lapping process in collaboration with industrial partners

1999 Establish integrated 300 mm wafer flatness thickness metrology system

2000 Commission XCALIBIR and develop as a calibration service

2002 Establish calibration service

Standards & Measurement Services

Calibrations:

Calibration methods to determine flatness and thickness characteristics are in development.

Testing:

300 mm wafers; polishing methods.

Development of Machine Tool Performance Models and a Machine Data Repository

Principle Investigator:
Alkan Donmez,
(301) 975 – 6618
alkan@nist.gov

Project Objective

In cooperation with industry and academia, to create tools to be used in a virtual manufacturing environment to simulate the complete manufacturing cycle so as to reduce the time for new product introduction.

Needs Addressed

To reduce design and production cycles, manufacturers need tools to predict their manufacturing capabilities before they start manufacturing prototypes for new products. Prototyping is usually an iterative process, taking considerable time and effort before the actual production can begin. It is a very costly effort, since, in general, the outcome cannot be predicted with existing design and analysis tools. Developing tools to simulate and carry out this iterative process in the virtual domain presents a unique opportunity for industry to reduce time for new product introduction.

Technical Approach

A major challenge in creating a virtual manufacturing environment is the representation of the performance and capabilities of various machine tools. Currently, there are no provisions in machine tool or CMM standards to store the performance information in any electronic media. The lack of standard representation prevents the creation of machine data repositories that are needed to test different simulation algorithms and to compare the performance of a given machine against many other machines within a similar category. In order to overcome this problem, in cooperation with industry and academia, first a data dictionary along with a standard format for representing meaningful machine tool performance data is being developed. A Web based repository is also being developed to accommodate this data format. In the next step, this repository will be populated with machine tool data from the project collaborators. In addition, remote data analysis and graphical representation tools are being developed within the repository.

Editor's Note: This is a NAMT project. A detailed description of all NAMT projects appears within the Office of Manufacturing Program's section. This project appears here because it directly ties into this division's core mission.

Manufacturing Engineering Laboratory

Intelligent Systems

Advanced Welding Manufacturing System (AWMS)

Leader: Rippey, William G.

Staff: Falco, Joseph A.
Gilsinn, James D.
Juberts, Maris
Russell, Robert T.

Total FTE: 1.17

1998 MEL Goals Supported

1. Laboratory research and development
3 Information-based National and International Standards and Measurements

Project Objective

Test and validate standards and measurement technology that will contribute to increased use of automated welding technology by manufacturers. Their criteria for use include increased productivity, higher product quality, return-on-investment, and ease-of-use.

Needs Addressed

Slow progress in advancing welding automation technology has limited the range of applications where machines can perform reliable welds in a cost effective manner. Standards for interoperability of specialized advanced control, sensor, hardware, and software components will contribute to better, less-expensive, welding systems for users, increased market share for compliant component vendors, and stimulation of new product development. Purchasers of welded products will benefit from lower costs and higher quality. Further, AWMS research activities with industry will develop new intelligent control systems for the arc welding industry and will allow us to anticipate standards needs for the near future.

Potential customers are users of automated welding technology in such manufacturing areas as shipbuilding, automotive and heavy equipment manufacturing, and building construction.

Technical Approach

In 1997 we built a prototype testbed for robotic Gas Metal Arc Welding (GMAW). It will be used for cooperative research to: 1) design control systems and conduct experiments for development and integration of advanced welding control and monitoring components, and 2) develop and/or validate interface specifications and standards for advanced welding manufacturing systems. We look for opportunities to convey results of experiments to industry for use in commercial products. We will work with the NIST Materials Reliability Division (MRD), and with technology suppliers and manufacturing users to test systems in the AWMS. We are participating in American Welding Society (AWS) standards committees to help convey our results and to contribute to standards development.

Prior Year Accomplishments

- Participated in AWS standards activities.
- Completed integration of AWMS components (robot, weld controller, cell controller)
- Demonstrated automated arc welding driven by the cell program, logged eletrical arc parameters.
- Wrote and presented “The NIST Automated Arc Welding Testbed”, W.G. Rippey, J.A. Falco, Proc. of 7th International Conf. on Computer Technology in Welding, July 8-11, 1997; San Francisco, CA. American Welding Society

FY 1998 Plans

- Perform cooperative research with industrial partners. A possible effort is the ongoing Welding Control Project sponsored by National Center for Manufacturing Sciences.
- Work with MRD Boulder to port their Arc Sensor Monitor to the AWMS and do welding experiments.
- Publish a report on the results.
- Verify AWMS architecture to accomodate: robotic seam sensor, adaptive change to power source parameters based on weld geometry, and to include weld plan language features for above.
- Replace or augment current Lincoln power source to allow custom adaptive control
- Port all three current controllers to ISAM templates.
- Participate in American Welding Society standards committee A9 on Computerization of Welding Data, monitor D16 (Robotics).

Five Year Plan Goals vs. Fiscal Year

1998 Port Boulder sensor technology to the AWMS and demonstrate it, participate in American Welding Society standards activities, port controllers to Intelligent Systems Architecture for Manufacturing (ISAM) templates.

1999 Add robotic weld seam sensor and seam tracking capabilities, experiments with path control based on seam sensor and arc length, including path adaptation, without advanced programming of robot path. Port AWMS technology to Robocrane, develop new technology for automated welding with Industry partners, enhance testbed capabilities for off-line programming, investigate issues of Standard for the Exchange of Product model data (STEP) standards for exchange of off-line data.

2000 Experiment with control of multipass welding, participate in AWS and/or STEP standards efforts for automated programming of welding, including testing of drafts and proposals on the AWMS testbed.

2001 Demonstrate scope of AWMS for standards validation including: sensors and sensor interfaces, process control, hardware component interfaces, welding process metrics, off-line programming, weld quality and inspection results data.

Standards & Measurement Services

Standards Committees

Bill Rippey has applied for membership in American Welding Society A9 Committee on Computerization of Welding Data, and has attended meetings as a working group member.

Enhanced Machine Controller (EMC)

Leader: Proctor, Frederick M.

Staff: Kramer, Thomas
Michaloski, John L.
Shackleford, William P.

Total FTE: .90

1998 MEL Goals Supported

1. Laboratory research and development
3. Information-based National and International Standards and Measurements

Project Objective

To develop, demonstrate, and validate open system interface standards that will reduce the life-cycle cost of controllers for machine tools, robots, and coordinate measuring machines.

Needs Addressed

The domestic machine tool controller market has all but been lost to foreign competition. Market share now stands at 13%. Competition in this market is currently based on keeping costs low, and edging out competition through proprietary barriers that make it difficult for products from competing vendors to coexist. The U.S. finds it increasingly difficult to compete on a cost basis, and it is widely believed that regaining market share will only be possible if the U.S. dominance in open systems and software can be applied to machine tool controllers.

Technical Approach

The EMC is participating in the Open Modular Architecture Controller (OMAC) User's Group, which includes members from the user, vendor, and technology provider communities. Our work focuses on Application Programming Interfaces (APIs) that are intended to provide a common interface to the core set of functions performed by controllers.

The technical work includes developing APIs in cooperation with controls builders and validating that the APIs serve their intended purpose through installations on production equipment.

Related Developments

Software developed by the EMC for application programming interface validation is being transferred to small and medium enterprises via the NIST Manufacturing Extension Partnership (MEP). The intent is to establish a low-cost means for transferring advances in machining technology to the small business community.

EMC software is also being used by the University of Maryland Computer Integrated Manufacturing (UM CIM) laboratory, to set up a simulated factory that includes robots and machine tools of various capabilities. The UM CIM laboratory research will focus on scheduling and resource management, using the EMC simulations as they would real machines.

Prior Year Accomplishments

- Papers published in FY 1997:
  - Kramer, T. R., and Proctor, F. M., "Feature-Based Control of a Machining Center," NISTIR 5926.
  - Proctor, F. M., Kramer, T. R., and Michaloski, J. L., "Canonical Machining Commands," NISTIR 5970.
  - Kramer, T. R., Proctor, F. M., Rippey, W. G., and Scott, H., "The NIST DMIS Interpreter," NISTIR 6012.
  - Stouffer, K., Proctor, F. M., Messina, E., and Albus, J., "An Advanced Deburring and Chamfering System (ADACS) Based on the Enhanced Machine Controller (EMC)," Proceedings of the 27th International Symposium on Industrial Robots, Milan, Italy, October 6-8, 1996.

- Szabo, S., and Proctor, F., "Validation Results of Specifications for Motion Control Interoperability," Proceedings of the SPIE Photonics East Symposium, Boston, MA, November 18-21, 1996.

- A one-day tutorial on RCS was given at the 1997 Intelligent Systems and Semiotics Conference. The tutorial included a history of intelligent control, case studies, and details of our RCS software.
- The Real-time Control System (RCS) software and documentation was posted on our Web site, http://isd.cme.nist.gov/proj/rcs_lib
- The EMC joined the industry-led Open Modular Architecture Controller (OMAC) User's Group, which includes representatives from General Motors, Ford, Chrysler, Boeing, Pratt and Whitney, Hewlett-Packard, ICON Industrial Controls, Cimetrix, and Advanced Technology and Research.
- In cooperation with EMC Consortium members, including Cimetrix, CIMplus, Cybo Robots, Delta Tau, Georgia Tech, Montronix, N-See Software, Rock Island Arsenal, and Shaver Engineering, the EMC team developed and published candidate interface specifications with a drive toward formal standardization.
- An upgrade to the EMC installed at Shaver Engineering, a one-man machine shop, was performed as a beta test of a full software controller. The goal of this installation was to build a controller using a minimum of proprietary hardware, and leverage the desktop computing market. The result was a savings of thousands of dollars in hardware, and the elimination of all purchased software costs.

FY 1998 Plans

- Pursue a pilot installation of the EMC software through the NIST Manufacturing Extension Partnership.
- Continue development and validation of the Open Modular Architecture Controller (OMAC) interface standards, issuing revisions based on production test site results.

Five Year Plan Goals vs. Fiscal Year

1998 Publish OMAC APIs

1998 Install EMC through MEP Pilot

1999 Add high-resolution logging to EMC code for accurate control systems performance measurement

1999 Install EMC at Navy Site, potentially Carderock

Standards & Measurement Services

Standards Committees

Open Modular Architecture Controller (OMAC) Users Group

Knowledge Engineering Program

Leader: Messina Elena

Staff: Amatucci, Edward G.
Coombs, David
Hong, Tsai Hong
Horst, John A.
Huang, Hui-Min
Kramer, Thomas
Nashman, Marilyn
Proctor, Frederick M.
Shackleford, William P.
Tsai, Tsung-Ming
Yoshimi, Billibon H.

Total FTE: 2.71

1998 MEL Goals Supported

1. Laboratory research and development
3. Information-based National and International Standards and Measurements
4. Internal Management: improve the management of technical programs including planning, prioritization, direction, and delivery of results.

Project Objective

To develop design and software engineering principles for building open-system architectures for intelligent control systems.

Needs Addressed

Lack of a general theory or design procedure for building open-architecture intelligent control systems is a barrier to their widespread use. Open architecture intelligent control systems, built from easily-integratable, reusable components, provide much greater extensibility, flexibility, and adaptability than typical closed, proprietary, single-function systems. The benefits that can be derived from open architectures for complex control cannot be fully leveraged by the vendors or users of these systems due to the lack of readily applicable methodologies and tools. Methodologies for designing and building intelligent control systems will improve productivity and capabilities in factories, power plants, transportation systems, and other complex applications by reducing the cost of building these systems, and expanding their potential capabilities. The current state-of-the-practice lacks the necessary techniques and tools for methodically designing, analyzing, and validating control for these extremely complicated systems. Hence, highly specialized engineers are required for the design, implementation, and maintenance of such challenging systems. Providing components that system builders can select based on their requirements and a framework to guide their composition into a system will enable use by a wider segment of industry. Tools which guide the construction of control systems based on more formal-principles will increase productivity and efficiency in their construction.

Technical Approach

In conjunction with other related division projects, we are developing methodologies and theories for intelligent control systems. Based on these theories, we will establish general design principles to guide development of open system architectures for intelligent control systems. We are investigating ways of providing life-cycle support to facilitate development based on the Real-time Control System (RCS) design principles. In order to ensure compatibility with existing practice and enhance usability by U.S. industry, we will generate a mapping from ISD open system architecture principles to commonly accepted software engineering terminology. We are experimentally developing a component-based approach to building intelligent control systems, with the eventual goal of supporting automated or semi-automated composition tools which enable construction of systems. Work for the Knowledge Engineering Program is funded with STRS and with an intramural grant from the ATP Component-Based Software Program. Collaborators include the NIST Information

Technologies Laboratory, Real-Time Innovations, Inc., Drexel University, Tulane University, SxS Research, Inc., and the Center for Excellence in Evolutionary Computation.

Prior Year Accomplishments

- Initiated collaboration with industry and academia in the research of advanced planning and control concepts. Funded research at Tulane University, SxS Research, and the Center for Excellence in Evolutionary Computation.
- Demonstrated the feasibility of utilizing commercial tools for development of RCS-based controllers (using Real-Time Innovations, Inc. ControlShell tool). A demonstration showed how basic components defined by RCS theory, such as for sensory processing and behavior generation, could be defined and composed together within a commercial tool.
- Commercial support for controller development based on RCS principles and utilizing existing components will increase the dissemination of this technology throughout U.S. industry.
- Developed generic specifications for a class of algorithms supporting part pose estimation and represented them in a formal language (EXPRESS). Formal specifications for components can enable their use as "building blocks" and is a pre-requisite for validating conformance to interface and functional standards.
- Published paper documenting component specifications for part pose estimation: Horst, J., E. Messina, T. Kramer, H. Huang, “Precise Definition of Software Component Specifications,” Proceedings of the 1997 IFAC Computer-Aided Control System Design Conference, Gent, Belgium, April, 1997.
- Built a framework for experimentation with development processes for constructing intelligent systems and for validation of the 4D/RCS sensory processing and world modeling components. The testbed is a coordinate measurement machine with vision system, providing an industry-credible scenario.
- Demonstrated a prototype system in which the location and orientation of a part arbitrarily positioned on the work surface of an inspection workstation is derived using the image from a camera and a synthetic image extracted from a solid model of the part.
- Published a report on software process requirements and strategies for supporting development of intelligent control systems. "Findings and Recommendations for a Software Development Process," NISTIR 5989, National Institute of Standards and Technology, Gaithersburg, MD, March 1997.
- Developed methodologies for planning and learning within the RCS reference model architecture, anticipating the need for interoperability standards in planning, scheduling, job assignment, and learning. (a) Studied the role of simulation in planning processes through a series of experiments in real-time planning. (b) Developed planning algorithm testbeds in two domains: manufacturing and autonomous vehicles. Began experimentation within both testbeds.
- Published a reference model architecture (4D/RCS) for perception including a sensory processing and world modeling system to support general purpose machine vision and other sensing technologies. Albus, J., "4D/RCS: A Reference Model Architecture for Demo III", NISTIR 5994, Gaithersburg, MD, March, 1997.
- Initiated design and development of knowledge base entities necessary to support outdoor mobility of intelligent vehicles and their subfunctions (e.g., navigation, perception, and control systems) including multi-resolution digital terrain maps. (a) Designed interfaces for the integration of digital terrain maps into knowledge base for planning (b) Developed utilities to aid in understanding requirements for updating digital terrain maps with higher resolution information extracted from sensors

FY 1998 Plans

- Initiate collaborative program with Drexel University for the engineering of intelligent systems architectures.
- Deploy on-line information system describing division CAD tools and expertise.
- Expand use of commercial tools for RCS development. Collaborate with vendors in order to improve accessibility and ease of use of RCS methodology for constructing controllers.
- Produce formal description of RCS components and architectures in an Architectural Description Language.
- Demonstrate dynamic access and manipulation of CAD model through Application Programming
- Interfaces for guiding part pose matching process.
- Demonstrate 2D perspective - 3D model pose estimation. Extend the part pose estimation subsystem to a hierarchical approach, using solid model information to prune lower-level matching with vision features.
- Dissemination of trial world model interface for description of obstacles encountered by vehicle sensors. Testing of interface through integration experiments with partner companies and universities.
- Demonstration of hierarchical mission and path planning system for autonomous vehicles.

Five Year Plan Goals vs. Fiscal Year

2002 Develop a design methodology for intelligent control systems.

1999 Define sensory processing component specifications in a formal manner.

2001 Develop a mapping from RCS theory onto commonly accepted Software Engineering principles, terminology, and methodologies.

2000 Define world modeling intelligent controller component specifications in a formal manner.

2002 Propose initial specifications for tools and software processes for building component-based intelligent control systems.

2001 Define additional intelligent controller component specifications in a formal manner.

2002 Propose draft standards for intelligent controller component specifications suitable for semi-automated or automated composition.

Standards & Measurement Services

Standards Committees

Tom Kramer is a member of three PDES/STEP committees. These are formally technical committees of:

- ISO TC184, SC4: Parametrics, Manufactured Products, and Manufacturing Technology.
- He is a member of the DMIS Object Technology standards development effort as well, which is under CAM-I.
- Tom Kramer is also a member of the Numerical Control BCL Standards Association.

Next Generation Inspection System(NGIS)

Leader: Rippey, William G.

Staff: Hong, Tsai Hong
Kramer, Thomas
Michaloski, John L.
Nashman, Marilyn
Szabo, Sandor
Yoshimi, Billibon H.

Total FTE 1.59

1998 MEL Goals Supported

1. Laboratory research and development
3. Information-based National and International Standards and Measurements

Project Objective

To achieve fast, accurate, and flexible geometric and dimensional inspection of manufactured parts. To maintain a next generation inspection testbed for developing open architecture controllers, developing capabilities that use multiple advanced sensors, testing of interface standards, and developing techniques for remote control and access of measurement devices.

Needs Addressed

Manufacturers in discrete-part machining industries need fast, efficient, accurate, and flexible methods for measuring the geometry of mechanical parts, particularly complex parts (e.g., transmission housings, air foils, turbine blades, engine valve bodies and seats, dies and molds). Benefits of improving the speed of current inspection methods include increased productivity, increased manufacturer throughput, and reduced inventories. Further, improved inspection technology will allow U.S. manufacturers to respond quickly new markets and to meet new market demands before foreign competitors do.

Much of the improvement in inspection methods will be achieved by using inspection probe technology recently developed and to be developed in the future. Currently it is difficult for manufacturers to add new probe technology to their controllers. This is slowing the adoption of new technology on their shop floors. Open architecture controllers will not only permit easier integration of advanced sensors into coordinate measurement machines and numerically controlled (NC) machine tools, but they will also promote efficient integration of other controller components, such as motion control, obstacle avoidance, computer aided design (CAD) software, and operator interface components. This will lead to better systems for users, easier and faster integration of component systems, more market opportunities for component suppliers, and lower prices through increased competition.

Technical Approach

The project has four areas of emphasis this year: standard interfaces for probes, vision-guided inspection with computer-aided design (CAD) integration, internet access to the testbed, and retrofit of a commercial controller.

Standard Interfaces for Probes. The National Center for Manufacturing Sciences(NCMS)-sponsored NGIS consortium sponsors a sensor interface working group to develop standard hardware and software interfaces between probing sensors and the control system, for both coordinate measuring machine (CMM) and NC applications. We will continue to work with this group to develop and validate the software specification on different classes of probes, including analog touch, laser, and capacitance probe. The resulting specification will be implemented not only on the NIST NGIS testbed, but also on the General Motors and Ford testbeds.

Vision Guided Inspection and CAD Integration. Our approach is to use vision sensors integrated with CAD part model data, to assist proximity inspection. The resulting capabilities are used for verifying parts, and locating features to guide proximity probes for high accuracy inspection.

Internet Access to Testbed. The goal is to investigate techniques for remote access to inspection devices so that a CMM can be used remotely as effectively as if it were on a user's shop floor. Technical areas will be: real-time command interfaces to the CMM controller, real-time access of inspection data produced by the CMM, and graphical programming tools.

Retrofit of Commercial Real-Time Control System (RCS) Controller. A commercial control vendor will integrate their RCS controller with the Cordax CMM. We will extend the controller through integration with vision processing, and maintain compatibility with NGIS consortium and ISD RCS technology. Through this exercise ISD will monitor and potentially influence commercialization of RCS. Internally it will test the feasibility of purchasing technology instead of developing it in-house.

Prior Year Accomplishments

- Gave two conference presentations, one Society of Manufacturing Engineers Publication.
- Coded a 3D pose determination algorithm using CAD model data. CAD data is used for pixel recognition, feature and part recognition and pose detemination.
- Developed and tested a hierarchical algorithm for grouping pixels into constant curvature line segments and grouping constant curvature line segments into closed objects in an image using Gestalt principles.
- Real-time camera calibration - demonstrated calibration of stationary camera using CMM plus probe.
- Internet-based Delivery of Measurement Services (IDEMS) project - demonstrated internet control of the CMM, and access to vision and probe data.
- NGIS Sensor API - chaired and hosted working group meetings, maintained the specification document.

FY 1998 Plans

- Retrofit of Commercial RCS Controller. Retrofit a commercial RCS controller to the CMM, integrate ISD RCS utilities, integrate vision sensors and ISD Dimensional Measuring Interface Standard (DMIS) interpreter.
- Internet Access to Testbed Demo semi-automatic (click on vision image) feature detection and inspection. Demo 3D interface and modeler for inspection programming. Demo 3D user interface for aligning the CAD model and vision data. Demo semi-automatic 3D model-driven inspection on test part (dovetail with vision/CAD work). Develop algorithm for automatic surface scanning of complex flat surfaces (transmission part) using vision
- Vision Guided Inspection and CAD Integration. Develop ability to perform vision-guided inspection of user specified features. Design and implement pose determination algorithms and evaluation algorithms. Design and implement a hierarchical grouping algorithm using CAD model for 1D, 2D and 3D feature recognition. Integrate Grimson's 2D feature matching/pose determination algorithm (implemented by John Horst for Mathematica) into the NGIS testbed. Design and implement real-time calibration algorithms for Visual Fast Inspection Task. Investigate issues related to using multiple cameras.
- Standard Interfaces for Probes. Develop, implement and test sensor APIs on NGIS testbed, and transfer to industry (Ford and GM). Publish the API specification, conformance testing specification, and conformance test results as NIST publications. Publish the draft Sync Bus specification as a NIST publication.

Five Year Plan Goals vs. Fiscal Year

1998 Demonstrate basic vision-CAD assisted inspection, do visual "road following"

1998 Enhance initial IDEMS internet demo

1998 Validate the NGIS SIM spec, begin Sync bus spec testing

1999 Upgrade testbed computing and inspection resources

1999 Do 5 axis CMM inspection (add continuous wrist), develop high-speed vision servoing algorithms, broaden application of RCS for inspection devices

1999 Demo 3D vision algorithms and feature-based programming and inspection

2000 Transfer vision-aided inspection technology to industry partner

2000 Perform cooperative internet research with partner,

2000 Develop new methods for visualization, analysis, and real-time use of inspection data

2000 Add ability to inspect more complex parts

2001 Demonstrate remote programming and control of vision-guided CMM from an industrial site

Standards & Measurement Services

Standards Committees

The NCMS/NGIS consortium is developing an interface specification for probes. NIST is testing the specification and is the editor and publisher of the document. The specification is currently scoped as an ad hoc standard to be used by the NGIS consortium members. The members will decide in 1998 if they wish to develop the specification as a formal industry standard, sponsored for example by IEEE.

Operator Interface

Leader Kent, Ernest W.

Staff: Coombs, David
Falco, Joseph A.
Flanagan, Patricia
Shackleford, William P.

Total FTE 1.80

1998 MEL Goals Supported

3. Information-based National and International Standards and Measurements

Project Objective

The issue addressed is that of human interfaces for development, planning, management, monitoring, and control of remote, distributed, or simulated manufacturing systems and their component activities. The first effort addresses these issues as developed in a laboratory setting for the Advanced Manufacturing Systems and Networking Testbed (AMSANT) facility using the Immersadesk virtual reality interface and other real-time graphics interfaces. A parallel effort has focused on the development of real-time, interactive, Internet-based, multi-user interfaces into manufacturing databases to support cooperative, remote access. A multi-user, real-time, interactive, shared-environment has been established which can be reached from anywhere on the Internet with PC-based equipment and standard phone lines. The general problem is to collect and present the relevant information, at the appropriate level of detail, and in the most efficient possible format, to a wide variety of remote users, operators, consultants and decision-makers, and to allow them to singly or interactively view simulations, manipulate remote databases, examine remote situations, and cooperatively control remote environments.

Needs Addressed

Manufacturing managers, planners, supervisors and other experts working in distributed and virtual manufacturing need the ability to interactively observe, discuss, modify and control manufacturing systems. The Operator Interfaces for Virtual and Distributed Manufacturing project will enable remote users to access necessary information in the most efficient manner, combining advanced display technology with human factors and actual information needs of potential users. This activity is an important part of the NIST System Integration for Manufacturing and Applications (SIMA) program, which helps U. S. industry take full advantage of developing advanced technologies in computation and communication. The operator interface portion of the program will enable users to access remote and virtual manufacturing information in the most efficient manner. It combines advanced communications technology and real-time, multi-user interfaces with an understanding of human factors issues and actual information needs of potential users.

Technical Approach

One of the approaches NIST is exploring for remote interaction is to construct remote "virtual environments" which are based on real-time text and near-real-time graphics. A low-cost operator interface previously developed utilizing web-based technology has been extended and implemented as a testbed for Internet-based control of real-world devices, near-real-time visualization of simulations and real devices, and remote, collaborative, real-time work. Remote users will interact richly with other remote participants and local NIST researchers in real-time, over the Internet, at low cost. Within the virtual environment, each remote participant is represented by a virtual entity called an 'avatar'. The avatar can interact both with other persons' avatars and with the environment in which all the avatars exist. The user sees on his screen what the environment represents to his avatar, and the environment reacts to the actions of the user's avatar. Hence, other participants also see the acts of the user's avatar reflected on their screens. The environment itself manages consistency so that when one person's avatar makes some change to the environment, moves something around, goes to another part of the environment, etc., all other avatars experience the result in an appropriate manner, transparent to the users. A unique feature of the NIST environment is that real-world device controllers may be represented by avatars in the environment. This allows bi-directional interaction between remote users and remote devices through their avatars.

Prior Year Accomplishments

- During FY97, this project developed new capabilities for supporting operator interfaces for remote and virtual manufacturing. A low-cost operator interface previously initiated utilizing web-based technology has been extended and implemented as a testbed for Internet-based control of real-world devices, near-real-time visualization of simulations and real devices, and remote collaborative real-time work.

FY 1998 Plans

- High-end Display: Maintain and evaluate the immersive 3D interface facility as a testbed for high-end, real-time graphics interfaces.
- Extend functionality of graphics interface: Add significant new capabilities to the graphics server component of the multimedia real-time environment.
- Low-end, multi-user, multi-platform remote interfaces: Deploy and evaluate a fully-implemented virtual environment.
- Develop graphics, text, and virtual objects necessary to implement a fully-functional, complete virtual environment (e.g., for some defined domain such as the National Advanced Manufacturing Testbed (NAMT), ISD, etc.) Deploy this environment on the Internet and evaluate ease-of-use of interface for naive users.

Five Year Plan Goals vs. Fiscal Year

2000 Bring real-time, multi-user, virtual environment online for public access.

2001 Evaluate and improve effectiveness of human interface aspects of online, virtual environment as a multi-user, collaborative environment for remote and virtual manufacturing.

2002 Enhance real-time, multi-media capabilities of virtual environment to keep pace with developing Internet technology.

Outdoor Mobility

Leader: Juberts, Maris

Staff: Balakirsky, Stephen
Coombs, David
Giauque, Charles
Gilsinn, James D.
Hong, Tsai Hong
Huang, Hui-Min
Lacaze, Alberto D.
Legowik, Steven A.
Messina, Elena
Moscovitz, Yigal
Murphy, Karl N.
Nashman, Marilyn
Shackleford, William P.
Szabo, Sandor
Tsai, Tsung-Ming
Wallace, Wendell W.
Yoshimi, Billibon H.

Total FTE: 10.70

1998 MEL Goals Supported

1. Laboratory research and development:

Project Objective

The specific objectives for this project are to develop, test and validate an open-systems architecture for an intelligent vehicle navigation perception and control system; develop performance measures for industries developing and using intelligent, sensor-based, vehicle-control-systems; and develop advanced core technology which extends the vehicle's dynamic navigation capabilities for off-road operations.

Needs Addressed

Open-system architecture standards are needed for industries that develop intelligent mobile vehicle systems for military security and surveillance and intelligent transportation systems applications. The need is for standard interfaces which encourage development and use of commercially available "plug-and-play" components and help to reduce cost and development time for system deployment and improvements.

The Department of Defense (DOD) Joint Robotics Program recognizes this need and is in the process of developing a Joint Architecture for Unmanned Ground Systems (JAUGS). The Real-time Control System (RCS), an open system reference architecture developed by the Intelligent Systems Division (ISD) at the National Institute of Standards and Technology (NIST), addresses this need and is being considered for use in the JAUGS standardization program. Before this can happen, ISD will have to show the DOD community how RCS complies with the DOD architecture requirements, and how it can provide commonality to hardware/software and interoperability components for a variety of ground vehicle platforms.

In addition to defining interfaces for subsystems and components, there is also a need for the development and demonstration of intelligent vehicle controllers through the use of advanced core technology being developed at universities, government labs and in industry. The United States Army user community, which is considering the deployment of autonomous robotic systems in the battlefield, has identified technology-development needs for such systems, which include reliable obstacle detection, tracking, recognition; more mobile off-road performance; night and all weather operations; and more autonomous tactical behaviors for single and multiple vehicles.

The emerging industries and the users need measures of performance for evaluating the technology being developed for intelligent mobile systems. Rapid technology evolution, driven by the availability of compact, low-cost, high-performance computers and new advanced sensors systems, requires the evaluation of autonomous and semi-autonomous control systems with intelligent behaviors. The National Highway Traffic Safety Administration (NHTSA) recognizes the need for evaluating advanced technology for it'sIntelligent Transportation Systems (ITS) and has sponsored work in ISD to develop a real-time measurement and roadway calibration system to evaluate on-vehicle crash avoidance systems for highways. In addition

NIST as part of the DOD program to develop technology for next generation unmanned ground vehicles, is being asked to develop measurement systems and conduct tests for evaluating this technology for military applications.

Technical Approach

We are developing an intelligent perception and vehicle navigation control system using the ISD Real-time Control System (RCS), an open system reference architecture. This development is a jointly-sponsored effort which leverages technology from the NIST Intelligent Machines Initiative program and support from the following other agency programs: the Army Research Lab (ARL) Demo III Unmanned Ground Vehicles (UGV) program, the Next Generation Autonomous Vehicle Navigation Control System (AUTONAV) research project between the German Ministry of Defense and the U.S. Department of Defense (DOD) and the AUTONAV/Department of Transporation (DOT) Crash Avoidance program.

RCS provides a systematic analysis, design, and implementation methodology for developing real-time, sensor-based, control systems. Functional task execution is viewed hierarchically with motor skill functions, like steering and speed control, performed at lower levels and coordinated actions between vehicles performed at higher levels. The control system uses sensory information to guide the intelligent vehicle in the execution of complex tasks. Planning for task execution and for adaptation to changes in the environment are also part of the total hierarchy.

Active and passive vision are the primary sensors for performing dynamic image perception analysis during navigation. Other sensors, like accelerometers, Inertial Navigation System (INS) and Differential Global Positioning System (DGPS), measure vehicle motion through the environment and provide a basis for precise localization of vehicles, targets, obstacles, and terrain features on a map database.

We are conducting advanced research and development in vision processing, hybrid, real-time, laser-range image LADAR/vision image data fusion for obstacle detection, recognition and avoidance, dynamic controls, mission planning and measures of performance. The AUTONAV research project agreement provides the mechanism for collaboration in developing a next generation perception and control system. This system will use advanced technology available from the research team consisting of NIST ARL, David Sarnoff Research Center, Universitat der Bundeswehr in Munich (UBM), and Dornier (Daimler-Benz). The core technology will be tested and refined using real-time simulation/virtual environments. We are developing plans and interactions with Demo III participants to define interfaces for integrating technology available from this program.

The outdoor mobility testbed vehicles (High Mobility Multipurpose Wheeled Vehicle (HMMWV) and others) will be used for testing , evaluating and demonstrating developed technology at test facilities and on actual roads while performing military or transportation specific scenarios.

Prior Year Accomplishments

- The AUTONAV research agreement between the U.S. Department of Defense and the German Ministry of Defense for the development of the next generation autonomous vehicle navigation perception and control was officially signed on November 8, 1996. ISD is a major research partner in the program which is expected to continue for four years and will support the DOD Demo III program objectives.
- ISD participated at all planning meetings for the startup of the five year DOD UGV Demo III program in FY 97. ISD is a major participant in this program and will support the Concerted Technology Thrust (CTT) initiative managed by the Army Research Lab (ARL). The CTT initiative group consists of NIST, JPL, ARL, and Ft. Knox BLWE.

- A preliminary version of an open-systems architecture for design of a next generation intelligent vehicle perception and control system was completed for the AUTONAV and Demo III programs. The jointly developed system will be called 4-D/RCS to reflect the 4-D image processing approach developed at UBM and the RCS architecture developed at NIST.
- Completed the exchange of available existing mature technology among participating researchers in the AUTONAV project.
- Completed integration of the Dornier Entfernungs-Bilt-Kamera (EBK) laser range scanner and the Carnegie Mellon University developed SMARTY obstacle mapping and avoidance software into the current vehicle mobility control system and conducted initial experiments and demonstrations for urban military operations at the NIST NIKE site.
  - Implemented algorithms for detecting positive and negative obstacles in LADAR data.
  - One version based on range profile along scan line. - Another version is a 1-D scan line implementation of Dornier approach.
  - A third approach combines the two algorithms.
- Demonstrated ditch detection.
- Generating local obstacle map (for path planning). Implemented local path planner. Integrated the obstacle detection/avoidance system to run on a laptop installed on the NIST HMMWV.
- Calibrated the correspondence between LADAR and Camera.
- Integrated the LADAR, camera data, and INS data. - Obstacles found in LADAR images are projected into camera image. - The projected obstacles in camera image are being recognized and tracked.
- Generated detailed demonstration scenarios and initial RCS hierarchy. Developed initial 4D/RCS templates for the Behavior Generation module.
- Obstacle Classification - Implemented several texture extraction algorithms. Installed these into Khoros.
- Demonstrated cluster analysis and classification of registered color/ LADAR (Attributes: color, texture, edges, height)
- Completed a round of data collection at Aberdeen. NIST/JPL/ARL-LADAR, stereo, Global Positioning System (GPS), INS data were collected.
- Designed interfaces between Jet Propulsion Laboratories (JPL) systems and 4D/RCS and between UBM systems and 4D/RCS.
- Installed mission generation, simulation, and visualization systems at NIST (i.e. Combat Information Processor (CIP), Modular Semi-Automated Forces (MODSAF), Army Research Lab (ARL)).
- Built prototype system demonstrating hierarchical planner which works at different resolutions.
- Obtained high-resolution (micro-terrain) for NIST and NIKE sites.
- Developed several utilities for visualizing LADAR data, including through the use of stereo. Developed utilities for generating polygonal terrain model from LADAR data.
- Started development of strategy for integrating a simulated autonomous vehicle within MODSAF, in collaboration with Ft. Knox Battle Lab Warfighting Experiment (BLWE) and ARL.
- Completed an Evaluation Test Plan for the National Highway Traffic Safety Administration (NHTSA) sponsored AUTONAV/DOT project for evaluating performance of advanced vehicular perception and control technology for applications as part of a driver assist run-off-road counter measure system to prevent crashes. Developed a data acquisition system for roadway tracking and calibration and demonstrated its capability to precisely track and map roadways using carrier phase DGPS, INS and a vision-based sideline tracking sensors.

FY 1998 Plans

- AUTONAV GENERAL Statement of Work: Develop the Phase 2 portion of Next Generation Autonomous Vehicle Navigation Control System (AUTONAV) to extend autonomous vehicle dynamic navigation capabilities for off road operations; implement the first version of the 4-D/RCS system architecture; develop and demonstrate the Baseline System for the 4-D/RCS perception and control system; integrate and test the new core technology developed by NIST and other AUTONAV partners under the Phase 1 portion of the agreement; develop the Phase 2 new core technology in hybrid LADAR/vision range image processing, new dynamic controls and mission/path planning; demonstrate improved off road autonomous performance.
- DEMO III GENERAL Statement of Work: Develop and implement version 1 of the intelligent system architecture for the Demo III next generation UGV program; develop interactions with Demo III participants to support program objectives; participate in conducting data collection exercises and performance measures for Demo III Conserted Technology Thrust (CTT) participants; work with the Demo III integration contractor to support architectural development activities, computer platform selection, and the transfer of advanced technology developed under. AUTONAV; implement and test the latest work in obstacle detection and avoidance, and low and high level mobility functions developed under AUTONAV (Task 1) and possibly by other project participants.
- AUTONAV/DOT GENERAL Statement of Work: Prepare final report for the National Highway Traffic Safety Administration (NHTSA) sponsored project in FY97 to develop and conduct tests with Measures of Performance (MOP) for evaluating advanced sensing and controls technology for effective collision avoidance systems. Prepare a proposal for extending the initial work to evaluation of run-off-road countermeasure systems.
- Analyze sensor data from off road experiments to develop camera stabilization requirements for LADAR and stereo vision cameras.
- Complete major NIST vehicle infrastructure upgrades by early February.
- Complete performance evaluation of the EBK LADAR data for detection of obstacles for Demo III.
- Investigate the use of commercial tools for facilitating 4D/RCS software development and collaboration.
- Continue to develop software for performing obstacle detection on EBK LADAR data for small positive and negative obstacles (Jan).
- Achieve agreement on mobility components of the 4-D/RCS architecture for Demo III (Jan.)
- Generate the 4-D/RCS interface requirements for perception and vehicle control for AUTONAV (Feb. 15) and Demo III (Jan 20).
- Provide first detailed draft of the 4-D/RCS templates and algorithms to UBM for study and comment (Feb.) Provide second draft of the 4-D/RCS templates and algorithms (end of March).
- Integrate and demonstrate obstacle detection using the EBK LADAR combined with INS/GPS using ISD developed obstacle detection and path planning algorithms (May). Complete integration of the UBM 4-D source code (Road Detection and Tracking (RDT) and Obstacle Detection and Tracking (ODT)) on the initial 4-D/RCS prototype and demonstrate autonomous road following and obstacle detection.
- Evaluate Franklin scanner and Lincoln Labs LADAR data and generate recommendations of their usefulness in Demo III.

- Implement and demonstrate the first working system of the AUTONAV 4-D/RCS version of a perception and vehicle control system to AUTONAV partners and ARL's sponsor (May).
- Complete integration of the JPL/4-D/RCS and UBM/4-D/RCS LADAR/Stereo-based obstacle avoidance system on the NIST HMMWV platform (by October).
- Convert microterrain data for NIST/NIKE into Virtual Geographical Information System (VGIS) format. Conduct experiments to measure requirements for georeferencing.
- Develop interfaces with Operator Control Unit (OCU) and with underlying VGIS databases.
- Develop and implement an initial Web-based interface to provide control of the vehicle.
- Integrate hierarchical planning algorithms into initial vehicle system. Provide obstacle avoidance based on detected obstacles. Begin accessing pre-existing terrain information for generating path trajectories. Develop initial cost functions for vehicle traversability based on terrain data.
- Investigate efficient means of capturing adequate amount of details for use in near-term obstacle avoidance, longer-term path planning, and for updating central digital terrain maps. Publish initial obstacle map interface specification to be filled in by sensory processing modules. Review with collaborators (JPL and UBM) and implement per specification.
- Integrate behavior generation (planning) algorithms into simulated vehicle within MODSAF. Deliver modules to Ft. Knox for their Demo III battle experiments.
- Continue development of 4D/RCS templates. Deliver documentation and code to partners.

Five Year Plan Goals vs. Fiscal Year

1998 Demonstrate first version of the AUTONAV 4-D/RCS architecture using perception, planning and control technology developed from from AUTONAV and Demo III activities.

1998 Develop Version 1.0 of an open system architecture standard for technology integration on Demo III.

1998 Integrate and test newly developed technology in FY97 on the testbed vehicle.

1998 Conduct interim tests of Phase 1 Core technology.

1998 Develop Phase 2 core technology for AUTONAV (higher level intelligent planning for off-road operations).

1999 Conduct interim tests of Phase 2 core technology.

1999 Develop Phase 3 core technology for AUTONAV (improve robustness for difficult off-road driving conditions).

1999 Demonstrate second version of the AUTONAV 4-D/RCS architecture using perception, planning and control technology developed from AUTONAV and Demo III activities.

1999 Develop Version 2.0 open systems architecture standard for technology integration on Demo III.

1999 Integrate and test newly developed technology in FY98 on the testbed vehicle.

2000 Demonstrate third version of the AUTONAV 4-D/RCS architecture using perception, planning, and control technology developed from AUTONAV and Demo III activities.

2000 Develop Version 3.0 open systems architecture standard for technology integration on Demo III.

2000 Integrate and test newly developed technology in FY99 on the testbed vehicle.

2000 Conduct interim tests of Phase 3 core technology.

2000 Conduct comprehensive evaluation tests of AUTONAV developed technology. This may extend into FY2001.

2001 Conduct comprehensive evaluation tests of AUTONAV and Demo III technology.

2001 Report comprehensive evaluation tests for Version 3.0 of the 4-D/RCS perception and control system.

2001 Develop Version 4.0 open systems architecture standard for final technology integration on Demo III.

2001 Integrate and test newly developed technology in FY2000 on testbed vehicle.

Standards & Measurement Services

Standards Committees

ISD serves on the DOD Joint Architecture for Unmanned Ground Systems (JAUGS) Architecture Standardization Working Group.

Reference Model Architecture

Leader: Scott, Harry A.

Staff: Amatucci, Edward G.
Horst, John A.
Huang, Hui-Min
Kramer, Thomas
Lacaze, Alberto D.
Messina, Elena
Meystel, Alex
Michaloski, John L.
Proctor, Frederick M.
Tsai, Tsung-Ming

Total FTE: 3.15

1998 MEL Goals Supported

1. Laboratory research and development
3. Information-based National and International Standards and Measurements

Project Objective

The purpose of this project is to develop a detailed design of a Reference Model Architecture for intelligent control of manufacturing processes. The NIST reference model architecture will be demonstrated, validated and evaluated through analysis and performance measurements of a simulated and prototype implementation.

Needs Addressed

The lack of a formal, consistent control architecture with a factory-wide scope is evidenced by characteristics of current implementations and their shortcomings. These include implementation of islands of automation exhibiting a low level of integration because of the absence of a common system architecture design model, functionality limited by the inability to integrate the components of multiple developers as the result of proprietary or non-standard interfaces, minimal reusable software components leading to higher cost, arbitrary differences in implementation techniques because a common model is not followed, and a lack of common development tools because of the differences among various architectural approaches. The development of the reference model architecture for intelligent control of manufacturing systems will directly address these needs. A common architecture will promote a higher level of integration and the standardization of subsystem interfaces. Since the architecture will no longer be a "moving target," the potential for software reuse is greater, as is the likelihood of creation of development tools that are useful across many applications. The results are cost savings in development and implementation of intelligent control systems for manufacturing.

Technical Approach

This program builds on the work to date in examining and understanding alternative architectural approaches and required functionality for implementing intelligent control systems in the manufacturing domain. A feasibility study that reviewed numerous architectures and draft specifications for portions of the architecture was completed and papers were published on architecture aspects. The project team has adopted a target architecture and resolution of remaining issues is underway. Work is in progress in the specification of a generic control module shell, which is a principal architectural component or building block and in definition of a standard message suite or Application Programming Interface (API) family. In preparation for the initial prototype implementation, significant effort was applied to the development of operational scenarios. The Next Generation Inspection System (NGIS) facility at NIST supported the initial prototype implementation. Ongoing development and testing continues in NGIS, as well as in a simulation environment and in the Hexapod, Welding and the mobility testbeds. These facilites support the testing of components of a factory, in which the concepts explored in the Enhanced Machine Controller (EMC) program, the Manufacturing Systems Integration (MSI) program, the Quality in Automation (QIA) program and the NGIS program are present under a single consistent reference architecture with standard interfaces developed or adopted for communication between architectural components.

Prior Year Accomplishments

- Published: "An Implementation Approach for an Intelligent Manufacturing Architecture," "An Open System Intelligent Manufacturing Architecture: the Concept and the Approach," "The NIST DMIS Interpreter," "Neural Network Based Planner/Learner for Control Systems," "Introduction to Integrated Learning/Planning Paradigm," "Unified Learning/Planning Automation: Generating and Using Multigranular Knowledge Hierarchies," "Multi-resolutional Planning with Minimum Complexity," "TEAM API for Open Architecture Modular Controllers," "The Inspection Workstation-based Testbed Application for the Intelligent Systems Architecture for Manufacturing," "Intelligent Manufacturing System Control: Reference Model and Initial Implementation", "Feature-based Control of a Machining Center," "NIST-RCS and Object-Oriented Methodologies of Software Engineering: A Conceptual Comparison"
- Prepared draft documents on Intelligent Systems Architecture for Manufacturing (ISAM) template versions and features and flowcharts on the template-based ISAM application development process
- Released a new version of the NIST Dimensional Measuring Interface Standard (DMIS) interpreter which includes new feature fitting functions from MSID Algorithm Testing System (ATS) and which removes dependence on an EXPRESS shema for DMIS and use of STEPTools
- Developed an initial feature-based system including a task controller, part controller, and graphical display
- Held several meetings with MSID to discuss leveraging of product information at the enterprise and shop floor levels and below and developed a strawman proposal for the flow of process and product information. Participated in additional meetings with MSID to address developing a common model of tooling for supporting control program simulations (Numerical Control (NC), DMIS, etc.) and possibly related manufacturing engineering activities (process planning).
- Developed a complex Computer Aided Design (CAD)-based and vision-based automatic part pose estimation system and integrated the initial version of this system into the Inspection Workstation (IWS) following Intelligent Systems Architecture for Manufacturing (ISAM) principles. The system includes the Servo level node on a VxWorks board, the Primitive level node on a SUN machine, and the operator interface and much of the sensory processing on another SUN, making this a truly distributed real-time control example
- Developed class implementations of Technologies Enabling Agile Manufacturing (TEAM) (superseded by Open Modular Architecture Controller (OMAC)) Interface Definition Language (IDL) API specification with sixty percent of the API coded and tested
- Developed messaging interface to Hexapod, and achieved successful integration with Shop Floor, Workcell and Hexapod simulation. Upgraded Workcell messaging interface to attain Common Object Request Broker Architecture (CORBA) 2.0 compliance
- Developed support for smarter scheduling/planning/resource management, with constraint-based (precedence and time-ordered) workcell scheduling integrated into the workcell
- Completed Revision v0.12 of the Open Modular Architecture Controller (OMAC) API specification for review at a meeting at General Motors Powertrain Headquarters in Pontiac Michigan

- Conducted extensive performance measurements of an experimental configuration of a template-based node with an integrated planner that included integration of an experimental planner with a full set of Reference Model Architecture nodes (Planner, Plan Selector, World Model, Sensor Processing, two Executors, and Value Judgment) for a single control level, the results of which are used to determine appropriate mappings of node submodules to operating system tasks, where the interprocess communication overhead cost can degrade performance
- Developed, in conjunction with Real-time Inovations (RTI), ISAM-compliant Primitive and Servo level control nodes that control motion of the CORDAX Coordinate Measuring Machine (CMM) in the Inspection Workstation. This is expected to lead to additions/modifications to the Real-time Innovations (RTI) commercial development tools for control system implementations that will support ISAM
- Developed a scenario jointly with MSID for the Inspection and Hexapod testbeds in support of the NAMT
- Framework Project. Developed inital scenarios for 4D/RCS testbed
- Established interfaces which enable node state and associated sensory data to be received, processed, maintained and utilized for control purposes within an ISAM node and conducted related experiments
- Demonstrated developments in the IWS testbed which included inspection operations on the TEAM part by the Inspection Workcell running several levels of control based on the Intelligent Systems Architecture for Manufacturing (ISAM) reference model and featured integration via CORBA into the NAMT Framework, remote operation from the Shop level operator in the AMSANT laboratory, live operation of the IWS and simulation, video feedback from the NGIS lab in the Shops building to the AMSANT lab via the network, a set of Java-based GUI capabilities permitting real-time display of graphic representations of data moving through the workstation control system interfaces and display of various graphs of operating variables from any web browser type environment

FY 1998 Plans

- Develop draft Reference Model Specification based on ISAM document and interface specifications.
- Document NGIS and Hexapod developments and update interfaces.
- Begin formalizing the concept of Job Sequencing as defined by NIIIP/Smart.
- Continue to work with RTI in development of tools to support ISAM compliant controllers.
- Evaluate NGIS and Hexapod implementations and prepare specifications recommended for standardization via Initial Manufacturing Exchange Specification (IMES).
- Integrate CAD-directed process planning and validation with IWS CMM testbed. Utilize the Silma Inspection tool for generating inspection plans, displaying and analyzing results of inspection and providing Framework with statistics and data.
- Continue to jointly develop TEAM/OMAC API specification with industry user group.
- Investigate Process Specification Language (PSL) efforts of MSID and utilize/participate where possible.
- Develop further the CAD API integration in the Inspection Workstation testbed. Proceed with more complex vision-based pose estimation algorithms requiring additional interaction with the CAD model through a procedural interface.
- Integrate generic planner and executor and generate path commands for lower level mobility system; apply results to Inspection Workstation testbed for evaluation of generic planner development

- Complete current template development for generic shell, integrating 4D/RCS concepts into ISAM node. Perform evaluations focused on Behavior Generation components including planning, value judgment, plan selection, job assignment and execution

Five Year Plan Goals vs. Fiscal Year

1998 Integrate CAD-directed process planning and validation with IWS CMM testbed and investigate related world model issues

1998 Prepare draft Reference Model Architecture Specification and interface specifications documents recommended for IMES

1998 Integrate generic planner and generic executor into ISAM generic shell and test generality in IWS and mobility testbeds

1998 Evaluate Reference Model Architecture performance in advanced, sensor-rich environments through integration of NGIS testbed vision capabilities

1999 Evaluate EMC-based testbed applications (Hexapod, Tetrahedral Robotic Apparatus (TETRA), Easily Manipulated Mechanical Armatures (EMMA)) and revise Reference Model Architecture

1999 Continue work with RTI aimed at provision of commercial ISAM system development support tools

2002 Pursue standardization of Reference Model Architecture

1999 Document CASE capabilities designed to facilitate implementation of Reference Model Architecture based systems

1999 Seek convergence among various ISAM support tools including RTI, Advanced Technology and Research Corp (ATR) and in-house ISD tools

2000 Develop and demonstrate remote/virtual manufacturing elements under Reference Model Architecture based control

2000 Document experiments in integration of remote/virtual manufacturing elements under Reference Model Architecture based control

2002 Apply Reference Model Architecture to domains of manufacturing other than discrete part, including welding, mobility and construction. Evaluate interfaces and develop specifications

Standards & Measurement Services

Standards Committees:

Manufacturing Technology Committee, ISO TC184 SC4 WG3 T11; Mechanical Product Definition

Committee, ISO TC184 SC4 WG3 T7; Ad Hoc Committee on Parametrics, ISO TC184 SC4 WG3

RoboCrane

Leader: Bostelman, Roger V.

Staff: Bunch, Robert
Dagalakis, Nicholas G.
Giauque, Charles
Goodwin, Kenneth R.
Jacoff, Adam S.
Marcinkoski, Jason
Wallace, Wendell W.
Weiss, Brian A.

Total FTE: 3.07

1998 MEL Goals Supported

1. Laboratory research and development
5. Customer satisfaction and program recognition

Project Objective

To use the RoboCrane for an Intelligent Machine Testbed to study and implement open architecture standards for intelligent machines. To work with industry and other government agencies to apply intelligent machine technology to a wide variety of applications including cargo handling, ship building, and environment restoration in field uses.

Needs Addressed

Manufacturers of large products such as ships, aircraft, railroad rolling stock, farm machinery, and construction equipment, as well as contractors building bridges, highways, high rise buildings, tunnels, and port facilities have many potential applications for heavy lift, precise positioning, and manipulation of tools over large work volumes. There are also many important tasks, such as radioactive and toxic waste removal, clearing mines and unexploded ordnance, deep sea salvage, mining, and drilling, that are inherently hazardous to human workers that can benefit from advanced crane technology.

The NIST RoboCrane is a revolutionary advance in crane technology. It transforms the crane from a device for simply lifting and placing heavy loads, to a robot capable of precisely manipulating objects and/or maneuvering power tools with position and force control in all six degrees of freedom.

The commercialization of this technology requires open system architecture standards that enable custom systems to be easily assembled and quickly integrated from a wide variety of actuators, sensors, and controller hardware and software. Interface standards that allow commercial components to "plug-and-play" will dramatically decrease the cost and reduce time-to-market for products with these capabilities.

Technical Approach

A RoboCrane testbed has been constructed with six degree-of-freedom control of a work platform suspended by cables driven by winches under computer control. This testbed is being equipped with a PC based Enhanced Machine Controller (EMC) incorporating a Real-Time Control System (RCS) reference model open-system architecture with a set of standard Application Program Interfaces (APIs). A variety of sensors and control methodologies will be used to test potential interface standards for the ability to support interchangability between functional modules for servo control, trajectory generation, constrained motion modes, discrete event logic, task sequencing, and operator interface devices such as joysticks, graphics programming environments, and telepresence display technology.

Efforts will be made to transfer technology to companies for commercial uses and to investigate potential applications in cooperation with other agency and industrial partners. Specifically, NIST will work closely with crane manufacturers and potential users to transfer early versions of this technology into practical applications in ship building, construction of highway bridges, radioactive waste clean-up, and undersea salvage operations.

Prior Year Accomplishments

- Under a contract with Office of Naval Research, NIST has designed and developed scale models of a RoboCrane for containerized cargo handling for loading and unloading ships at sea and to and from a Mobile Offshore Base (MOB). Static and dynamic analysis was performed using Deneb Robotics Teleoperted Graphical Robot Instruction program (TGRIP) simulation tool. Research was conducted to include other crane technologies instead of or as a part of the MOB lift-on/lift-off operations.
- Work with Grey Pilgrim has also resulted in the development of a 10.1 M long EMMA manipulator for nuclear waste tank clean-up. This system was a result of the DOE Hanford Tanks Intiative project in 1997.
- A Cooperative Research and Development Agreement (CRADA) has been re-established with Grey Pilgrim, LLC to develop a flexible, serpentine, cable-driven manipulator known as EMMA (Easily Manipulated Mechnical Armatures) to manipulate a foveal-peripheral camera system for remote operation or manipulate other tools for a variety of robotic applications.
- A telepresence vision system is being designed to provide the operator with full remote control capability of the RoboCrane. Pan-tilt-zoom cameras and monitors have been installed as part of this system.
- Under a contract with Advanced Technology Research (ATR), ATR and NIST have developed and tested a preliminary EMC compliant control system for the Tetrahedral Robotic Apparatus (TETRA) utilizing the Profibus sensor network.
- A prototype high bay RoboCrane apparatus has been designed using state-of-the-art solid modeling Computer Aided Design (CAD) software (Pro/Engineer). This prototype has been constructed and attached to an existing NIST bridge crane for the purpose of investigating RoboCrane control techniques over a work volume 22.9 M high. Dynamic (hoistable) load stability tests have been conducted to measure the stability of the system at it's extreme depth (22.9 M) with a minimal reference frame (6.1 M).
- A six-meter RoboCrane testbed has been constructed that can precisely manipulate cast iron pipes, steel beams, fifty-five gallon drums, scale model bridge elements, and perform precise mating and joining operations. Power tools such as grinders, welders, and saws have also been manipulated. Six-axis joystick interfaces have been implemented on the RoboCrane for one and two-operator control modes. A LabView development and diagnostic display has been incorporated into the operator interface. Encoders and tension sensors have been installed to measure cable lengths and forces. A commercial graphics programming system has been installed and modified and graphical off-line control has been demonstrated for semi-autonomous welding and grinding applications.
- Explored development of innovative machine designs for large-scale manufacturing and construction. (i.e. Stewart Platforms systems, EMMA) (a) Developed long reach EMMA, including design, fabrication, and control, to be used as a testbed (b) Began design and implementation of a telepresence vision system with virtual reality displays that facilitate remote control by human operators

FY 1998 Plans

- Work with crane manufacturers and the Navy to develop RoboCrane applications for cargo handling.
- Work with the Department of Energy and industry to develop and test the RoboCrane and EMMA manipulator systems for extracting nuclear waste from underground storage tanks.
- Work with crane manufacturers and potential users to design, develop, and market RoboCrane systems.

- Demonstrate cargo acquisition, transfer, and placement at crane heights of up to 22.9 M.
- Develop operator panels, network communication software, and operator assisted control strategies.
- Continue development of the RoboCrane telepresence system.
- Design and implement an EMC controller on the EMMA manipulator for nuclear waste extraction.
- Design and install the EMC controller on the RoboCrane testbed upon testing of the preliminary EMC controller on TETRA.

Five Year Plan Goals vs. Fiscal Year

2000 Develop a full set of open architecture interfaces that can serve as potential interface standards.

2001 Test potential open architecture interface standards in a number of applications including welding and assembly of steel structures. Develop techniques for measuring performance of RoboCrane systems.

2001 Work with crane manufacturers to transfer RoboCrane technology into the marketplace.

2002 Work with crane manufacturers and users to adopt a full set of open architecture API standards and performance standards.

Standards & Measurement Services

Standards Committees

Dr. Nicholas G. Dagalakis is a member of one International Working Group and one National Review Committe and three subcommittess of the National Review Committee.

- International Committee: ISO/TC184/SC02/WG04 Programming Methods and Language for Manipulating Industrial Robots;
- National Review Committee: R15 Robotics Standards; Sub-committees: SC05 Robot Performance; SC06 Robot Safety; SC07 Simulation/Off-Line Programming

Characterization, Remote Access, and Simulation of Hexapod Machines

Principle Investigator:
Albert J. Wavering
(301) 975-3461
albert.wavering@nist.gov

Project Objective

To measure, extend, and demonstrate the capabilities of hexapod machines through the collaborative development and use of metrology, remote access, and simulation tools.

Needs Addressed

Rapid production of quality contoured parts requires machine tools that combine speed, accuracy, stiffness and multiaxis versatility. A new class of parallel-actuated machine tools based on the Stewart platform mechanism presents new possibilities for meeting these needs. However, much remains to be learned about the characteristics of these 'hexapod' machine tools before they will see widespread production application. Industry workshops have highlighted the need for an increased understanding of the performance characteristics of these new machines, standard test methods and measurement procedures, modeling and simulation tools, remote access capabilities, and examination of controller and integration issues.

Technical Approach

The NAMT Hexapod project team, in collaboration with external partners, is performing work in the areas of characterization, remote access, and simulationóusing an experimental prototype hexapod machineóto address the needs identified above. NIST researchers are participating in a recently formed Hexapod Users Group to coordinate research activities and share results with machine tool builders, users, and researchers.

Performance evaluation techniques are being developed using existing standards as starting points. Modifications to these test procedures will then be identified as necessary to make them more appropriate for hexapod machines. Performance enhancements such as improved calibration and feedback metrology techniques are also being investigated. For remote interaction, high-speed communications links, such as ATM networks, are being explored to provide real-time transfer of audio/video and sensor data to researchers at remote sites. Internet-based tools are also being implemented to provide similar services at a lower cost, but with some compromise in performance. To examine controller and integration issues, an open architecture controller is being installed on the hexapod at NIST. Modeling and simulation capabilities are being developed in an incremental fashion to build tools needed to help perform such tasks as NC program verification and investigation of errors. Web-based access to some of these animation and simulation tools is also being explored.

Editor's Note: This is a NAMT project. A detailed description of all NAMT projects appears within the Office of Manufacturing Program's section. This project appears here because it directly ties into this division's core mission.

Manufacturing Engineering Laboratory

Manufacturing Systems Integration

Advanced Process Control (APC)

Leader: Wallace, Evan K.

Staff: Flater, David W.

Total FTE 0.70

1998 MEL Goals Supported

1. Laboratory research and development.

Project Objective

The objective of the APC Testbed project is the analysis, testing and validation of the Experimental Advanced Process Control framework components produced by Advanced Micro Devices and Honeywell. Analysis will include scalability assessment and assessment of APC Framework requirements for infrastructure and associated systems such as Manufacturing Execution Systems.

Needs Addressed

As the semiconductor industry is driven to the limits of its fabrication technology in an effort to achieve higher densities and performance for its integrated circuits, the need for more responsive and precise control of fabrication processes has become acute. These same higher performance chips have provided processing power which can be used to build a new process control system to support today's more stringent control requirements. The APC consortium has done just that with its Advanced Process Control (APC) Framework.

The APC Framework is a modular, distributed system with an architecture that supports extensive reuse of its components. While such an architecture can make efficient use of its programmers, it may also impose intense performance requirements on some of its components and on its supported and integrated infrastructure. Tools and tests are needed to study these requirements.

Other industries also have a need to more precisely control manufacturing processes, in order to meet tighter emissions requirements, reduce waste, increase yield and protect greater investment in manufactured materials.

Since advanced process control adds new dynamic elements to production control, it will put new demands on systems such as Manufacturing Execution Systems with which it may interact. We will try to answer "What new interface requirements will result from this? "

Technical Approach

The approach we have taken has a number of parts but three main thrusts:

1. testing of the infrastructure based on the APC Framework interfaces, its architecture and some characterization of its typical use;
2. testing of an APC Framework implementation with some emulated components;
3. testing of an APC Framework implementation in a discrete part application.

A toolkit, called Manufacturer's CORBA Interface Testing Toolkit (MCITT), was built to facilitate the creation of code to test a communication infrastructure based on the Common Object Request Broker Architecture (CORBA). An examination of the APC Framework architectures and interfaces was performed. This combined with information from fabrication floor users was used to develop test cases. From these test cases, tests were built, run and analyzed on two different hardware platforms. The results of these tests were then forwarded to the authors of the APC Framework to guide further development and installations.

A second set of tests will be designed and executed using the APC Framework components themselves. Emulated machine interfaces will be built (probably by extending code generated by MCITT) and then different APC Framework system configurations will be run and tested. Subsequent analyses of these tests will offer additional insights into potential bottlenecks within the system as well as requirements on related systems.

Stress tests conducted to date were performed on a Solaris-based Object Request Broker (ORB) which simulated some of the usage requirements which the APC Framework components may impose when fully implemented in a wafer fabrication facility. These tests included: 1) testing the number of connections possible between a single client-server pair, 2) testing latency for two differently-sized messages to transit between a collocated client-server pair, 3) testing loading effects of many clients simultaneously retrieving data from a single collocated server, 4) testing the effects of sending an invalid object reference as argument, and 5) testing latency for moderately sized messages to transit between a locally distributed client-server pair. The complete suite of tests will also be performed on a Microsoft Windows NT based ORB during the first quarter of Fiscal 98.

In addition, we will identify an application for advanced process control within the discrete part domain and build an emulated workstation using the APC components provided by Honeywell/AMD. We will then document this with an emphasis on the effects resulting from the architecture of the APC framework as designed by Honeywell/AMD.

Results of these efforts and additional analysis of the APC Framework will be documented in several reports.

Related Developments

ATP

The NIST Advanced Technology Program (ATP) has funded the APC consortium to solve high-risk problems associated with manufacturing process control.

MCITT

The Manufacturer's CORBA Interface Testing Toolkit (MCITT) was developed, in part, to serve the needs of the APC Testbed project. While it now stands alone as its own project, the toolkit will still be important to the needs of the APC Testbed project in FY98. It will be used for testing and to create emulated APC components in support of the validation activity.

NAMT Framework

The validation goals and methods used in the APC Testbed project are similar to those of the NAMT Framework project. Since the integrating infrastructure is also the same, integration of the NAMT Framework implementation and the APC validation implementation shouldn't be difficult. This integration will further the goals of both projects by broadening the overall manufacturing system environment in which each subsystem can be tested. Note that this integration is likely to be an out-year activity.

OMG MES work

Principals involved in this work are also involved in efforts at the Object Management Group (OMG) to develop standard interfaces to Manufacturing Execution Systems (MES). This will enable both efforts to develop compatible interfaces.

SEMATECH

SEMATECH, the Semiconductor Manufacturing Technology Industry Consorium, has recently released its Computer Integrated Manufacturing Applications Framework (CIMF). The APC Framework is being designed to be compatible with the SEMATECH CIMF.

Prior Year Accomplishments

- Created and executed stress tests with MCITT, simulating resource intense uses of Sun-based CORBA infrastructure in scenarios suggested by the APC Framework interfaces.
- Developed MCITT software to support stress and scalability testing.
- Acquired and installed hardware and software environment required for APC components.

FY 1998 Plans

- Study Honeywell/APC components–their architecture and behavior under different test configurations.
- Install APC components.
- Create and execute stress tests with MCITT simulating resource intense uses of Microsoft Windows NT based CORBA infrastructure suggested by the APC Framework interfaces.
- Identify application of advanced process control within the manufacture of discrete parts.

Five Year Plan Goals vs. Fiscal Year

1999 Integrate with NAMT Framework implementation.

2000 Document the results of analysis and use of APC Framework Components.

2002 Implement workcell.

2001 Design an emulated workcell incorporating the APC components and exploiting their capabilities for process control.

2002 Perform comparative analysis of process control strategies.

Application Protocol Development Environment (APDE)

Leader: Lubell, Joshua

Staff: Phillips, Lisa
Sauder, David A.

FTE: 1.30

1998 MEL Goals Supported

1. Laboratory research and development.
3. Information-based National and International Standards and Measurements.
5. Customer satisfaction and program recognition

Project Objective

To accelerate the development of the Standard for the Exchange of Product Model Data (STEP, ISO 10303) and to aid Application Protocol (AP) developers in creating AP specifications more efficiently, with higher quality and at a lower cost.

Needs Addressed

Current practices for AP development require extraordinary labor expenditures on behalf of developers to define the requirements and document the required technical elements. Our initial customers are defining data exchange standards that meet an industrial need within U.S. and international standards organizations. However, efficient use of limited technical resources is not being made because the set of tools at their disposal requires many manual and error-prone operations. Further, their distributed work teams complicate the configuration management of these complex technical specifications.

STEP specifies a description of product data throughout its life cycle in a computing platform-independent manner. An AP in STEP defines the information requirements for a particular area of design, manufacturing, engineering, or product support. APs provide a neutral representation for sharing product data among dissimilar software applications.

Technical Approach

An integrated suite of software tools is being established to assist STEP AP development. These software tools use an information registry at NIST consisting of STEP and STEP-related documents and data. Documents are represented in the Standard Generalized Mark-up Language (SGML), using document type definitions (DTDs), developed specifically for STEP, to enable "intelligent" access and better transferability among differing computer platforms. The AP development process includes defining information requirements, modeling that information, verifying that the information models are correct, identifying how these requirements are satisfied by STEP core concepts, developing test criteria for implementations, and documenting all components in a mandated format. An integrated toolset will be provided to support each of these process steps.

Prior Year Accomplishments

- Demonstrated APDE's capabilities at ISO TC184/SC4 (Industrial automation systems and integration: Industrial Data) meeting using "live Internet" connection, and to delegation of Japanese publishing executives visiting NIST.
- Presented the following papers: 1. "The SC4 Short Names Registry," Sixth International Express User Group Conference, Toronto Hilton, October 4, 1996. 2. "SGML Application Development: Tradeoffs and Choices," SGML'96 Conference, Boston, November 18-21, 1996.

- Added an on-line request form to the Short Names Registry, resulting in a reduction of time spent by document authors and NIST in creating unique identifiers for entities in STEP information models.
- Built prototype workflow management system employing an SGML repository, demonstrating the benefits of SGML for workflow applications.
- Implemented a publicly viewable Web gateway for accessing primary information requirements concepts ("Units of Functionality") from STEP APs.
- Released new versions of the STEP Document Type Definitions (DTDs) and supporting applications for document preparation.
- Developed several productivity tools for SGML authoring using the STEP DTDs. The tools reduce the amount of SGML tagging required by authors.

FY 1998 Plans

- Conduct AP publishing requirements and DTD analysis workshops at the February 1998 ISO TC184/SC4(International Organization for Standardization Industrial automation systems and integration technical committee; Industrial Data subcommittee) meeting in Orlando FL.
- Present the paper "SGML on the Web: A Tale of Two Sites" at the SGML/XML '97 conference in Washington DC, December 8-11, 1997.
- Provide support to AP210 (STEP Application Protocol, "Electronic assembly, interconnect and packaging design") project team, enabling them to use NIST's SGML tools to produce their draft international standard document.
- Develop "SGMbuild" publishing application, enabling the publication of SGML-tagged STEP standards conforming to ISO and SC4 documentation requirements. Use SGMbuild to create AP210, the largest STEP standard to date, exceeding 3000 pages of text and diagrams.
- Convert all existing STEP AP and integrated resource international standards from their legacy formats into SGML using the STEP document type definitions.
- Publish the paper "Using SGML to Prepare STEP Standards", documenting the SGML authoring environment implemented for STEP.
- Gather requirements and build a workflow application for managing administrative tasks in SC4, using the technology developed in the "XML for Workflow Management" project.
- Develop Web gateway for validation of STEP information models and their corresponding data, providing remote access to NIST-developed and public domain third party tools.

Five Year Plan Goals vs. Fiscal Year

1998 This project is not expected to continue beyond FY 1998.

Standards & Measurement Services

Standards Committees:

ISO TC184/SC4, ISO/IEC JTC1/WG4 (International Organization for Standardization/International Electrotechnical Commission Joint Technical Committee 1, Working Group 4: Information Technology — Document Description and Processing Languages)

Computer-Aided Manufacturing Engineering

Leader: McLean, Charles R.

Staff: Chen, Chin-Sheng
Iuliano, Michael
Jones, Albert T.
Lee, Yung-Tsun Tina
Leong, Swee K.
Shao, Guodong gshao

Total FTE 2.55

1998 MEL Goals Supported

1. Laboratory research and development.

Project Objective

The overall goal of the project is to lower manufacturing costs, reduce development and delivery times, and improve product quality through the development and use of advanced manufacturing engineering tools. The project will develop an integrated tool kit that can be used to plan part production and accurately predict product quality and process performance before a job is released to the shop floor. A key focus of the project is to develop a manufacturing data validation methodology. Other project objectives include development of a functional definition of the manufacturing engineering process, and an integrated tools architecture.

Needs Addressed

Integrated computer-aided manufacturing engineering environments are needed by internal Department of Defense (DoD) manufacturing sites, primes and subcontractors, and non-defense commercial manufacturing facilities. Although many software tools are currently available for manufacturing engineers, they do not work together and cannot be readily integrated. This lack of integration significantly diminishes the productivity of manufacturing engineers, reduces the quality of parts production, and increases the time it takes to plan the production of a part or an assembly. Examples of these tools include: producibility analysis software, computer-aided design software, process planning systems, simulation/modeling packages, and product data management systems. Data generated by these current tools is not guaranteed to produce a part correctly the first time. New integrated engineering environments (i.e., tool kits) must be developed to solve this problem. For widespread implementation, environments must be based primarily upon the integration of commercially available engineering tools. Customers include Navy Manufacturing Technology and Joint Strike Fighter Program, defense and civilian manufacturers, and software applications vendors.

Integrated engineering tool kits would increase the productivity of engineers performing process planning tasks, producibility analyses, designing manufacturing systems, evaluating quality costs, conducting design trade-off studies, and reducing tools integration time. A recent study indicated that improved manufacturing and industrial engineering support tools could save the Department of Defense about $300 million per year ("Manufacturing Systems Strategic Plan," Report of the Manufacturing Systems Committee, DoD Manufacturing Science and Technology Program, March 1993). The benefits realized from this project would be applicable to Defense as well as civilian manufacturing.

Technical Approach

The project will assess industry needs, with respect to manufacturing engineering tools and tool integration. It will develop methodologies, architectures, interfaces, and databases for integrating engineering tool environments. Prototype integrated engineering tool kits will be constructed from commercial products. New methods, models, tools, data base structures, and reference databases for integrating design, manufacturing engineering, and production operations will be developed. Solutions will be validated at industry sites. The principal elements of the technical approach are: 1) identify and address critical industrial needs through collaboration, 2) develop solutions to engineering tool integration problems, 3) construct prototype environments using commercial products, 4) validate results through industrial testing of system implementations, 5) specify and promote needed industry standards, and 6) facilitate the rapid commercialization of new technology.

Related Developments

- ISO TC 184/SC4 standardization activities, particularly ISO 10303-21 (Implementation methods: Clear text encoding of the exchange structure),10303-203 (Application protocol: Configuration controlled design),10303-213 (Application protocol:Numerical control process plans for machined parts),and 10303-227 (Application protocol: Plant spatial configuration).

Prior Year Accomplishments

- "A Virtual Manufacturing Testbed", A. Jones, M. Iuliano, Proceedings of the 1997 IEEE International Conference on Systems, Man, and Cybernetics, Oct 12-15, Orlando FL.
- "A Simulation-based Production Testbed", A. Jones, M. Iuliano, Proceedings of the 1997 Winter Simulation Conference, Dec 7-11, Atlanta GA.
- "The Role of Product Data Management in the Manufacturing Engineering Toolkit", NIST IR 6042. M. Iuliano August 1997.
- An Analysis of STEP AP213 for Usage as a Process Plan Format", M. Iuliano, A. Jones, S. Feng. - NIST IR 5992. March 1997.
- "Controlling Activities in a Virtual Manufacturing Cell", M. Iuliano, A. Jones, Proceedings of the ASME Winter Simulation Conference, 1996, Coronada CA.
- "Using Simulation to Validate Engineering Data", M. Iuliano A. Jones, Proceedings of the Deneb Robotics Users Group Conference 1996, Detroit, MI.
- "Using the Manufacturing Engineering Toolkit in the Virtual Manufacturing System" M. Iuliano. NISTIR 5913, Nov 1996 (VHS video tape).
- Gave Presentation at the Defense Simulation and Imaging Conference in May, 97 at the Sheraton Crystal City, Arlington VA.
- Developed new machine tools and tooling simulation models for the Hurco milling machine using Planning Activities Resources and Technologies (PART) process planning system and DENEB Virtual Numerical Control (VC).
- Received collaborators in-kind contributions including test parts, process data, simulation machine and tooling models, industrial practices and knowledge.
- Completed a collaborative project with Raytheon Electronics System and Tecnomatix to evaluate process planning and Numerical Control (NC) generation system.
- Signed CRADA agreements with Black & Decker, Ohio Aerospace Institute, Litton Amecom, Microcompatibles, California State University Pomona, CimTechnologies, Deneb Robotics, and Framework Technologies.
- Established new collaborators to evaluate tool kit technology, e.g., Raytheon Electronic Systems.
- Established Computer-Aided Manufacturing Engineering (CAME) Consortium for coordinating collaboration and dissemination of project results with active participation from DoD, industrial users, researchers, and software vendors.

FY 1998 Plans

- Implement CAME manufacturing engineering tool kit at NIST machine shop facility
- Develop post-processors for new machine tools
- Develop new models for machine tools, tooling, fixtures and test parts
- Hold a workshop to review requirements and specifications documents
- Develop manufacturing data validation methodology document
- Develop process planning specification for machined part
- Develop manufacturing engineering business process models
- Develop CAME Impact Study Cost Model
- Develop CAME design interface specification document
- Update CAME functional requirements document
- Collaborate with the Joint Strike Fighter program office, Boeing and Lockheed Martin to identify the needs of the manufacturing data validation requirements

Five Year Plan Goals vs. Fiscal Year

1998 Integrate data projects

1999 Install CAME toolkit at alpha site

1999 Demonstrate CAME toolkit

2000 Commercialization phase

2000 Roll out CAME toolkit

2001 Interface standard activities

Computational Metrology

Leader: Shakarji, Craig M.

Staff: Christopher, Neil
Diaz-Plungez, Cathleen
Rosenfeld, David

Total FTE: 2.45

1998 MEL Goals Supported

1. Laboratory research and development.
3. Information-based National and International Standards and Measurements.
5. Customer satisfaction and program recognition.

Project Objective

To provide industry with an efficient, reliable, and standardized means to test the performance of coordinate metrology software to obtain uncertainty estimates and traceability.

Needs Addressed

The increasing role of coordinate metrology in manufacturing inspection makes critical the need for a systematic, rigorous means to characterize the uncertainty associated with such conformance testing. Beyond the question of traceable uncertainty estimates in point acquisition methods (research in PED) is the difficult problem of quantifying the performance of the mathematical software embedded in the coordinate measuring systems. Less-than-optimal, feature-extraction software is often the cause of wrong conformance determination, resulting in higher production costs and poor quality control. Additionally, traceability, according to ISO definition, requires quantified software uncertainty estimates which, when made overly-conservatively, lead to a competitive disadvantage.

Manufacturers and software vendors have expressed great interest and involvement in NIST's Algorithm Testing and Evaluation Program for Coordinate Measuring Systems (ATEP-CMS) which addresses some of industry's need for software testing, but they have voiced the clear need for expanded services. Specifically, NIST's ATEP-CMS service has been used widely in testing least-squares geometrical fitting software for regular geometries, while industry has also been requesting tests for minimum-zone, maximum inscribed, and minimum circumscribed fitting software as well as for tests of complex surface fitting software. These fitting criteria better reflect the tolerance definitions per American Society of Mechanical Engineers (ASME) Y14.5-1994. Some customers have used the performance evaluation that ATEP-CMS provides to demonstrate traceability as a necessary part of gaining ISO 9000 accreditation, thereby removing many international trade barriers.

The project research also allows us to maintain the technical competence to meet other national needs, such as providing technical support to ASME B89 and ISO TC 213 standards bodies. Additionally, we have the need to continue providing industry and other government agencies with technical consulting in this field.

Technical Approach

At the core of the test service is the Algorithm Testing System (ATS), an integrated software package that performs the three major parts of the test: generating data sets, computing reference solutions, and comparing results. Customized data generation simulates typical form and measurement errors. Both the customer's software and the ATS then compute least-squares geometrical fits associated with these data sets. The customer's results are analyzed with respect to NIST's reference fits and a performance evaluation is then made.

Several improvements to existing functions, including the implementation of multi-precision software, should provide reference least-squares fits with uncertainties in the defining parameters at less than 1e-12 times the characteristic size for regularly sampled geometries. We are also developing new reference algorithms for the ATS in answer to widespread industrial desire for additional testing algorithms that fit maximum inscribed, minimum circumscribed, and minimum zone features. These algorithms are quite different in nature than the least-squares approach, as they seek to optimize a function that is not smooth and whose global minimum is perhaps not unique and is hidden among several nearby local minima. The optimization technique underlying these new reference algorithms is the simulated annealing method, which our research shows to be well suited to these problems. Uncertainty estimates should be brought into a range comparable with the least-squares cases.

Porting both the ATS and the ATEP-CMS service to a web-based format will ensure efficient access for our industrial customers. A new design-of-experiments module will automate the data generation process and will have options for either ASME or ISO standardized tests. A demo section will allow users to learn the testing process and unofficially self-test their algorithms for in-house validation. An underlying Oracle database will allow for tracking industrial testing trends.

As the digital modeling standard (ASME Y14.4) emerges allowing use of Computer Aided Design (CAD) systems in tolerance specifications, we can build upon our accomplishments in geometrical curve and surface fitting to expand the ATEP-CMS service to complex surface algorithms. A collaborative effort employing ITL, academic experts, and the hiring of guest researchers, will allow us to meet industrial needs with a quality service in this rapidly growing field.

Related Developments

- Two standards bodies (ASME B89.4.10 nationally and ISO TC213 internationally) are poised to release CMS software testing standards in 1998. The ATEP-CMS project is involved in these standards bodies and is developing the testing service in harmony with these emerging standards.
- MEL's Precision Engineering Division is researching uncertainty associated with point coordinate acquisition from Coordinate Measuring Machines (CMMs). This couples with our research, as individual point errors propagate to errors in the substitute geometry reported by the fitting software. We are continuing to work jointly on this generalized problem.
- EEEL's Electricity Division has developed a web-based calibration database automating the administrative aspects of calibration testing. We can make use of this work in our own development of a web-based testing service.

Prior Year Accomplishments

- Developed an approach to design of experiments. The approach was incorporated into the released ASME B89.4.10 draft national standard in the section on a minimal sampling plan. This approach was implemented in our manual design of data set parameters.
- Documented ATS algorithm strategies in a research report for the NIST Journal of Research.
- Presented the ATEP-CMS service to the International Dimensional Measuring Interface Standard (DMIS) users group and at the Society of Manufacturing Engineers (SME) precision metrology conference.
- Provided technical consulting to several industrial customers as well as the Navy and Air Force.
- Contributed to ASME and ISO draft standards for software performance evaluation.
- Created multi-precision software package that can now be implemented to lower uncertainty in ATEP-CMS process.
- Completed initial versions of minimum-zone and maximum-inscribed and minimum-circumscribed algorithms.
- Completed ATEP-CMS software performance tests of U.S. industry inspection software (ongoing service).

FY 1998 Plans

- Continue research in complex surface fitting techniques.
- Publish report on relationship of ATEP-CMS to ISO 9000 conformance.
- Participate in ISO/TC 213 activities to release ISO 10360-6, the international standard on CMM software testing.
- Publish ASME B89.4.10 standard on CMS software performance evaluation.
- Incorporate minimum-zone, maximum inscribed and minimum-circumscribed reference algorithms into the ATS in order to expand our ATEP-CMS service.
- Develop reference-quality minimum-zone, maximum-inscribed, and minimum-circumscribed fitting algorithms.
- Implement improvements to the ATS least-squares algorithms.
- Port the ATS to a web-based format.
- Put ATEP-CMS service online so customers can access information, request tests, and provide test parameters via the Internet.
- Provide the ATEP-CMS Special Test Service to industrial customers.

Five Year Plan Goals vs. Fiscal Year

1998 Document relationship of ATEP-CMS to ISO 9000 conformance.

1999 Publish ASME B89.4.10 standard on CMS software performance evaluation.

1999 Publish ISO 10360-6.

1999 Port the ATS tool to a web-based format.

1999 Port the ATEP service to a web-based format.

1999 Develop, implement, and begin providing minimum-zone, maximum-inscribed, and minimum-circumscribed testing services.

2000 Define tolerancing and measurement methods for complex surfaces.

2000 Develop reference-quality fitting algorithms for complex surfaces.

2002 Participate in ISO TC 213 WG 10 on software testing and CMM uncertainty standards.

2002 Develop and populate database with industry inspection methods/form-errors relationships

2002 Implement design-of-experiments module into ATS with continued revisions.

2002 Provide ATEP-CMS service to industry.

2001 Expand ASME B89.4.10 to include varied fit objectives.

2002 Implement complex surface fitting test service to ATEP-CMS.

2002 Establish new national standards for statistical and complex-surface tolerancing

Standards & Measurement Services

Testing:

- NIST is providing the ATEP-CMS Special Test Service to industry by performing CMS software tests and evaluations consistent with emerging national standards. Currently, testing is offered for least-squares fitting algorithms for lines, planes, circles, spheres, cylinders, cones, and tori which covers most of the callouts specified in the geometric dimensioning and tolerancing standard (ASME Y14.5-1994).

Standards Committees:

- ASME B89.4.10 Methods For Performance Evaluation of Coordinate Measuring System Software
- ISO TC 213 WG 10 Dimensional and geometrical product specifications and verification
- ASME Y14.5 Dimensioning and Tolerancing (GD&T)
- ASME Y14.5.1 Mathematical Definition of Dimensioning and Tolerancing Principles

Design/Process Planning Integration (DPPI)

Leader: Nederbragt, Walter W.

Staff: Feng, Shaw C.
Zhang, Yuyan

Total FTE 2.00

1998 MEL Goals Supported

1. Laboratory research and development
5. Customer satisfaction and program recognition

Project Objective

Enhance interoperability and performance between the design environment and process planning environment in order to facilitate the creation of new products.

Needs Addressed

Experienced designers often are able to create successful designs because of their knowledge of manufacturing practices. However, for less experienced designers it is often advantageous to the designer to get input from experienced personnel in the manufacturing department. Ideally, the designer should be able to get manufacturing or process planning input at all stages of design to aid in the design process. This can become burdensome to manufacturing personnel.

With the advent of Computer-Aided Design (CAD), designers can do a large amount of design work using advanced modeling tools. This includes finite element analysis, solid geometric modeling, conceptual modeling, and kinematics/dynamic analysis. On the manufacturing side, Computer-Aided Manufacturing (CAM) software enables manufacturing personnel to create manufacturing plans and get manufacturing cost estimations with the aid of a computer.

Although computer assisted manufacturing and design can significantly improve design and manufacturing practices they do not collaborate well. To improve a product during the design phase, the designer should have manufacturing, cost estimation, and design tools that all work together. This would enable the designer to make more sound judgments at all stages of product design. Since most design and manufacturing systems are based on proprietary software, a standard for creating interoperability between different CAx systems should be created. This would significantly reduce the cost of integration for manufacturers. On a broad scale, the use of this technology will enable more rapid response of American manufacturers to changing product and market needs, which will let them remain competitive while responding to these changes.

Technical Approach

Both manufacturing and design take place at many different levels. The design phase includes several stages such as creation of specifications, development of conceptual designs and development of detailed designs. Specifications are developed early in the design phase to communicate the necessary characteristics of a product. At the conceptual design phase initial, design ideas are created. These ideas can include sketches of a preliminary product layout, straw-man concepts, etc. Finally, the detailed design phase includes the detailed assembly and part drawings/models.

Manufacturing planning also is an evolving process where conceptual manufacturing plans evolve into detailed plans. Conceptual manufacturing may include suggestions for the best manufacturing process, suggestions for part purchases from vendors, and preliminary cost estimations. Detailed manufacturing plans contain the necessary process information for construction of the product, and a detailed cost estimation. This gives the manufacturer an understanding of the costs involved prior to starting the manufacturing process.

The goal of this project is to enable communication between design and manufacturing during the complete design phase. This communication needs to take place at many levels. These levels can include content, design rationale, negotiation, and communication. At the content level, engineering details such as features, constraints, geometry, and processes are communicated. The design rationale level covers issues such as design history, plans, and goals. The negotiation level covers negotiations between different agents. Finally, the communication level covers additional information beyond design rationale and content. This may include an engineering ontology for design/process planning communication, and information on the sender and recipient.

FY 1998 Plans

- Analyze and document the coverage capabilities of Application Protocol (AP) 213: Numerical Control Process Plans for Machined Parts.
- Develop taxonomy of design/manufacturing "features" to represent the information that needs to be exchanged. This requires analysis of existing taxonomies in both design and manufacturing to indicate the types of information that needs to be communicated.
- Co-sponsor/organize a workshop on design/process planning integration and interoperability. This workshop will help in understanding industry needs and will aid in developing an agenda for future research and development in standards related activities.
- Survey current methods and technologies used in design and process planning. This includes conceptual design tools, detailed design tools, cost estimation systems, and process planning systems.

Five Year Plan Goals vs. Fiscal Year

1999 Survey current methods and technologies used in design and process planning.

2000 Develop a taxonomy of design/manufacturing "features" to represent information that needs to be exchanged.

2001 Co-sponsor/organize workshops on design/process planning integration and interoperability.

2002 Publish results in Journals, Conferences, and Workshops.

2002 Implement, validate, demonstrate, and deploy design/process planning interoperability methods.

Engineering Design and Process Planning Testbed

Leader: Sriram, Ram D.

Staff: Christophe, Bochenek
Chung, Pyeong-Kwan
Hart, Peter F.
Lyons, Kevin W.
Racz, Janusz W.
Szykman, Simon

Total FTE 4.70

1998 MEL Goals Supported

1. Laboratory research and development
5. Customer satisfaction and program recognition

Project Objective

To provide a platform for: testing and validating design and process planning methodologies, storing and accessing design and process plan repositories using appropriate standards (current and emerging), aiding in supply-chain integration, helping in technology transfer to the U.S. industry, and bringing together industrial, academic, and government researchers in a standards-based environment.

Needs Addressed

Various studies indicate that errors made during early design stages tend to increase the cost of the end product exponentially. To effectively compete in the global markets, the U.S. industry should produce quality goods at a competitive price. To do so involves

taking appropriate measures to produce innovative and robust designs, which should include all information needed for other engineering tasks. There are several impediments to achieving this goal. Examples include: inadequate capabilities for small design and manufacturing companies to exploit the national information infrastructure; lack of access to adequate design histories (both product and process), which leads to duplication of effort and costly delays and results in non-optimal design schedules; inadequate transfer of technology of the state-of-the-art tools; and techniques for engineering design and process planning.

Technical Approach

Technology Transfer. The engineering design and process planning testbed will be used to foster collaboration between various industries, government agencies, and academic institutions. As part of the Defense Advanced Research Project Agency, Rapid Design Exploration and Optimization/Manufacturing Automation and Design Engineering (DARPA, RaDEO/MADE) supported program we have developed cooperative agreements with Boeing Defense and Space Group (Seattle, Washington), Boeing Company Information and Support Services (Seattle, Washington), Boeing D&SG Helicopters Division (Philadelphia, Pennsylvania), and Stanford University (Stanford, California). Work with Boeing Defense and Space Group, Seattle, involves the integration of traditional computer-aided design (CAD) systems with analysis packages through a shared database, using either Standard Exchange of Product Data/International Organization for standardization, 10303-209 (STEP ISO AP-209) or appropriate extensions. The generative design project at Boeing Company focuses on generation of design alternatives using knowledge-based techniques for reasoning about designs. There are several aspects to the MADE-smart project at Boeing D&SG Helicopters Division: intelligent agents to coordinate users, design tools, and related legacy systems; multidisciplinary optimization; and natural language techniques for generating computer interpretable specifications. The Stanford Ontology project aims to develop a design net device modeling environment for modeling various aspects of engineering devices.

CAD Tool Evaluation. This activity has acquired several state-of-the-art commercial computer-based design tools. Examples of these are: IDEAS Master Series, MicroStation and Pro-Engineer. Visiting engineers from academia, government, and industry can use these tools. We will be using these tools to study various standards related issues, in particular, information transfer in a collaborative design environment.

Design and Process Plan Information Storage and Access. The NIST Design Repository involves the development of standard mechanisms for storing and accessing design product and process knowledge. These standard mechanisms will be used to create repositories containing design case studies and associated process plans that will be acquired from various sources such as industry and academic partners. The Design Repository is being developed as a layered structure, with the lowest layer being an object-oriented database management systems and the top layer consisting of various knowledge-level, editing utilities (e.g., interfaces for creation, editing, and browsing of design repositories). A knowledge layer provides representations of function, behavior, and structure (including geometry); these representations will be extended to include design rationale, and intended use.

Internet-Based Computer-Aided Design and Manufacturing (CAD/CAM). This activity is investigating the Internet as a delivery mechanism for CAD/CAM capability, with particular emphasis on the needs of small businesses in industry. Small businesses can be viewed as one of the main potential consumers of Internet-based CAD/CAM services due to limitations of in-house expertise and financial resources. A study of the needs of small businesses has not previously been undertaken, in part because many large companies do not place high priority on small business needs, and the smaller companies do not have resources to do so. As part of NIST's focus on serving U.S. industry, this work involves a case study to investigate the needs of small businesses in the area of Internet-based CAD.

Prior Year Accomplishments

- Published: Proceedings for Network-Centric CAD: A Research Planning Workshop
- Organized Workshop: Network-Centric CAD: A Research Planning Workshop
- Organized workshop: Workshop on Tools and Technologies for Distributed and Collaborative Design
- Organized workshops: NIST Design Repository Workshop
- Published: An Information Modeling Framework to Support Design Databases and Repositories (1997 American Society of Mechanical Engineers (ASME) Design for Manufacturing Conference)
- Developed prototype web interface to an engineering design repository.
- Managed DARPA's RaDEO program in design and manufacturing.
- Continued working with DARPA's RaDEO contractors.

FY 1998 Plans

- Publish papers in leading journals, conferences, and workshops. Disseminate results of NIST workshops through publication of workshop proceedings.
- Develop knowledge-based design interfaces to traditional CAD tools.
- Complete design and manufacturing scenario with industry collaborator using the Internet as the primary vehicle for information exchange.
- Help with program management of DARPA's RaDEO program in design and manufacturing.
- Continue working with DARPA's RaDEO contractors. Install various software modules developed by collaborators.
- Continue working on the NIST Design Repository. Develop additional knowledge representations, extend interfaces and create new repositories.

- Co-sponsor/organize workshops on design-process planning integration, systems interoperability: CAD to CAx, knowledge-based interoperability. These workshops will help in understanding industry needs and will aid in developing an agenda for future research and development in standards related activities.

Five Year Plan Goals vs. Fiscal Year

1999 Investigate Internet-Based Computer-Aided Design and Manufacturing technologies.

1999 Help with program management of DARPA's RaDEO program in design and manufacturing.

2000 Co-sponsor/organize workshops on collaborative design, design repository, design-process planning integration, solid interchange format.

2002 Publish results in Journals, Conferences, and Workshops.

2002 Develop knowledge-based design interfaces to traditional CAD tools.

2002 Continue working with DARPA RaDEO contractors. Install various software modules developed by collaborators.

2002 Continue working on NIST Design Repository.

Enterprise Resource Planning Interfaces

Leader: Barkmeyer, Edward J.

Staff: Algeo, Mary Beth
Christopher, Neil
Feng, Shaw C.

Total FTE 1.20

1998 MEL Goals Supported

1. Laboratory research and development.
3. Information-based National and International Standards and Measurements.
4. Internal Management

Project Objective

To determine what interfaces to Enterprise Resource Planning (ERP) systems are most appropriate for early standardization and to define an appropriate role for NIST in the development of those interface standards.

Needs Addressed

ERP systems form the information and transaction backbone of modern manufacturing enterprises, capturing and maintaining almost all the data used in implementing the order fulfillment process. These systems capture specifications for the materials, resources and procedures to be used in manufacturing a given product. They capture and track orders, shipments and inventories. They plan and track acquisition, use and cost of all resources needed for making, packaging and shipping product — materials, tooling, equipment, labor, and related funds.

Largely as a consequence of their development history, modern ERP systems tend to be very large software complexes built around a collection of carefully integrated databases. This makes them very expensive to procure, install and maintain in a given corporation, and very difficult to integrate with other decision-support systems that provide support for other engineering and planning functions. In addition, functions such as optimizing supply chain order placement and materials flow effectively require communication between the ERP systems of the producers and the consumers.

Thus there is a need to modularize ERP system services, in order to reach the Small-to-Medium Enterprise (SME) market, where the cost of procuring and deploying the large ERP system as a unit is prohibitive. There is also a need to provide means for interworking with decision support systems that were not developed by, or in partnership with, ERP systems vendors. Finally, there is a need to provide for interworking the ERP systems of suppliers and customers. All of these needs can be met, or significantly ameliorated, by providing standard interfaces to ERP information and services.

While this need is widely recognized by both users and vendors of ERP systems, the only existing standard interface work has been directed toward the interfaces between the ERP systems and the business systems for procurement, accounting and labor management. And in the manufacturing software arena, government support has been for 20 years a sine qua non for the development of technical interface standards. So we believe that there is a need for NIST to lead in defining a standards roadmap in the ERP area.

Technical Approach

The scope of an ERP system is so large that it is very difficult to determine where to begin the standardization process. A typical ERP system provides over 1000 specific application program interfaces. So we are pursuing the following approach:

- Model the use of ERP systems — the major enterprise activities that use ERP systems, the specialized application software that is used in performing those activities, and the nature of the ERP information and services used by those activities.

- Identify groups of information and services that are used together in these enterprise activities.
- Identify the groups used most frequently and most importantly in enterprise activities involving applications not provided by the ERP vendor.
- Initiate the development of standard interfaces for those information and service groups in a standards body composed of ERP-vendor, ERP-user and Decision Support System-provider organizations.

The first year of effort is dedicated primarily to the first activity: understand the principal uses of ERP systems. We are researching the state of the practice - what are the principal enterprise activities that utilize ERP information resources and services, what information resources do they use, and how do they use these resources in relation to one another. We are investigating the decision support activities and tools that are linked to, or part of, ERP systems.

We are investigating the relationship of ERP systems to other systems in which there are active interface standardization efforts, particularly to Product Data Management (PDM), Computer-Aided Process Planning and other process specification systems, Manufacturing Executive Systems (MES) and systems for electronic commerce. We are investigating the availability of prototype standards and existing standardization efforts in these areas, such as Electronic [business] Data Interchange (EDI). The objective of this study is to provide a framework in which multiple ERP-related interface standardization efforts can be planned. It is expected that this work will also identify a scope of objects suitable for immediate standardization efforts.

A further objective of the work is the development of guidelines for the modularization of ERP systems into useful “components”, each of which provides a set of interfaces that accomplishes a closely related set of functions.

Process specification and analysis systems support the process engineering activities of a manufacturing enterprise. Those systems interact with the ERP information/service groups supporting management of process specifications and the delivery of process specifications to the factory floor. A special effort of this project is to study the role of the ERP systems in supporting manufacturing execution (ERP system as MES) and the related interfaces to process specification systems.

An important additional aspect of the first year of effort is to define the most useful roles for NIST in making such standards happen. Most of the activities beyond the first year will depend on this result.

Related Developments

- NAMT Framework for Distributed Manufacturing project — is participating in development and testing of standards relating to Manufacturing Execution Systems (MES), including the SEMATECH CIM Framework and the OMG MES work, ISO WD10303-219 inspection information, and the OMG PDM interfaces. This will provide a testbed for ERP-MES interfaces.
- NAMT Internet Commerce for Manufacturing project — is developing activity models and standards requirements, scenarios and pilots for outsourced circuit-board manufacture. Many of the activities have ERP aspects and some of the standards requirements are for ERP interfaces.
- Manufacturing Enterprise Information project — is defining scope, modularity and views of the enterprise-wide function and information model. ERP information and service groups should “fit” in this model.
- NIIIP/AMMPLE — is a pilot project for vertical integration of supply chains in production of specific weapons systems. It provides specific reference instances for ERP activities and interface requirements.

FY 1998 Plans

- NIST White Paper on process specification and MES activity and information models. (Work performed in collaboration with the NAMT Framework Project.)
- NIST ERP IMES White Paper, recommending a NIST role and further NIST activities in the ERP interface area.
- Initial draft ERP Activity Model paper

Five Year Plan Goals vs. Fiscal Year

1998 Publish a report on the activity and rough object/service framework for use of ERP systems

1998 Publish a report on the activity and rough object/service framework for process specification.

2000 Publish a report on the most important information/service modules and initiate interface specification standards for those modules.

2001 Harmonize ERP, MES and process engineering information and service models and harmonize the interface standards.

Standards & Measurement Services

Standards Committees

- Object Management Group, Manufacturing Domain Task Force—initiated a study group to determine which ERP areas should be addressed by new OMG work items; currently working on a specific interface set for the relationship between ERP systems and Manufacturing Execution Systems (MES). Through the NAMT Framework project, NIST participates as co-chair of the ERP working group with SSA, an ERP system vendor.
- ISO TC184/SC4/WG8—home of the MANDATE project (ISO 15531), which is working on exchange standards for manufacturing resource data and models for the integration of EDI standards (contracts, shipments, manifests, etc.) with manufacturing software systems.
- Open Applications Group (OAG)—a consortium of users and vendors of ERP software systems. A primary activity of OAG has been the development of standard packages of information for import to and exports from ERP systems, called "Business Object Documents".

Information Protocols for Design

Leader: Sriram, Ram D.

Staff: Allen, Robert H.
Bardhan,Tridip
Biswas, Arpan
Bouras, Abdelaziz
Hart, Peter F.
Jurrens, Kevin K.
Kaing, Serge
Lyons, Kevin W.
Narahari, Yadati
Pratt, Michael
Sudarsan, Rachuri

Total FTE 8.90

1998 MEL Goals Supported

1. Laboratory research and development.
3. Information-based National and International Standards and Measurements.
5. Customer satisfaction and program recognition.

Project Objective

To develop appropriate standards and protocols for interoperability of design tasks with each other and with other engineering tasks, such as process planning and production engineering. The primary focus of this project will be on developing data exchange mechanisms between traditional computer-aided design (CAD), augmented CAD (e.g., analysis, virtual reality (VR), knowledge-based CAD (design for assembly), and manufacturing engineering systems such as process planning.

Needs Addressed

Interoperability between traditional CAD systems has been the primary focus of the International Organization for Standardization (ISO)10303 Standard for the Exchange of Product Data (STEP). However, release 1 of STEP only allows the transfer of CAD models in terms of geometry and topology. This reflects the state-of-the-art of CAD systems as they were several years ago. There is a strong industrial demand for STEP to be brought up-to-date in terms of the improved capabilities of traditional CAD systems. In addition, the emergence of new design support systems has introduced interoperability issues in that these new systems are not tightly coupled with current traditional CAD applications. An example of this is VR systems, which are being viewed as a natural extension or enhancement to current CAD systems; these are also known as Augmented CAD systems. Yet, today very different methods to visualize and manipulate the underlying product model are used. This results in data and information that cannot be shared by other engineering and manufacturing systems. This incompatibility is highlighted when engineers, working with a product model within a VR application, generate important information that assists in defining assembly processes or results in modifications to the product model. Other examples include interoperability problems between various traditional CAD systems (i.e., commercial CAD tools) and between CAD and other manufacturing software. Until these barriers are addressed and solved there is little likelihood of industry acceptance of these tools and emerging technologies.

Technical Approach

This project will develop prototype information exchange mechanisms to demonstrate the interoperability between traditional CAD systems and between CAD systems, and other manufacturing systems (e.g., process planning system) utilizing state-of-the-art support technologies. The project is divided into several tasks as described below.

Short Term Parametrics: The goal here is to enhance ISO 10303 (STEP) for the capture and exchange of Parametric, constraint-based, and feature-based models, such as those generated by all major modern CAD systems. This will be achieved by developing schemas for capturing the above information. These schemas will be developed in cooperation with other international projects which have similar scope. Pilot implementations will demonstrate the validity of the above models.

Design to Process Planning: This task involves the exchange of information between traditional CAD systems and process planning systems. Our goal is to develop an information model that will aid in sharing design and process planning data.

Knowledge-Based Design Interoperability: This task involves the exchange of information between knowledge-based design systems, and between knowledge-based design systems and traditional CAD systems. An object-oriented model is being developed. This model will be tested with at least two commercial, knowledge-based, design tools.

Augmented CAD to Traditional CAD and Assembly Planning: This task involves the development of exchange standards for data interchange between CAD systems (such as ProEngineer), augmented CAD systems (e.g., simulation-based design), and assembly process planning. The initial effort (coordinated with Washington State University) on augmented CAD systems will be on the creation of trajectory component orientation information (process data), swept volumes, and assembly sequencing data that can be merged with the part representation. Various STEP-based resources will be used.

Solid Interchange Format (SIF): This task involves the use of STEP's generic resources for the development of a standard for the exchange of CAD data with Rapid Prototyping systems, which have been developed for producing physical structures in layers (e.g., 3D Printing).

Related Developments

- ISO 13584 (Parts Library). The Parts Library standard (under development) will enable the provision of standard parts data from libraries for use in a design environment. The parameterization capabilities of ISO 14959 are needed for the effective use of this standard.
- Open CAx Architecture for Interoperability (OCAI) project (led by National Center for Manufacturing Science (NCMS), Ann Arbor, MI. The OCAI project is adopting a different (Application Program Interface–based but probably complementary approach to a closely related problem. Mike Pratt is acting as a technical consultant to OCAI, which effectively started in January 1997. Output from this project is likely to be of direct utility to the Parametric work.
- NIST is the agent for the Defense Advanced Research Project Agency (DARPA) contract on Design to Analysis Integration. We are working closely with Boeing on the STEP AP 209 integration.
- Dr. Richard Fike's group at Stanford University, Knowledge Systems Laboratory, has been developing various kinds of ontologies for design analysis integration. These are being utilized in the knowledge interchange format work. NIST is the agent for DARPA and this project.

Prior Year Accomplishments

- Published papers in leading journals, conferences, and workshops.
- Investigated models for exchanging data between traditional CAD and process planning software.
- Installed, configured, and tested an augmented CAD system/Virtual Assembly Design Environment (VADE) at NIST.
- Completed development of a first draft of an explicit geometric constraints schema for ISO.
- Sponsored workshops for determining industry needs for design-process planning integration and collaborative design.
- Organized workshops for determining industry needs for solid interchange format, assembly level tolerancing, and knowledge-based interoperability.

FY 1998 Plans

- Publish papers in leading journals, conferences, and workshops.
- Demonstrate interoperability of traditional CAD (using at least two commercial CAD tools) and augmented CAD.
- Investigate models for exchanging data between traditional CAD and process planning software.
- Develop interface specifications for traditional CAD to knowledge-based CAD information exchange.
- Implement geometric constraints schema (developed in Fiscal Year (FY) 1997) within a commercial CAD tool.
- Organize workshop to determine industry need for interoperating augmented CAD (VR) systems and other CAD systems.

Five Year Plan Goals vs. Fiscal Year

1998 Organize workshop to determine industry need for interoperating augmented CAD/VR systems and other CAD systems.

2000 Develop information models for exchange of traditional CAD data with augmented CAD systems.

2000 Develop detailed information models for Parametric, variational, and featured-based CAD data.

2000 Input results of above into ISO TC184/SC4.

2000 Use current STEP generic resources and propose a solid interchange format (SIF) for solid free form fabrication.

2001 Develop information models for data exchange between traditional CAD and knowledge-based CAD.

2002 Implement prototypes to demonstrate data exchange between CAD and manufacturing assembly planning.

2002 Develop information models for data exchange between CAD and manufacturing assembly planning.

2002 Input results of above into ISO TC184/SC4.

2002 Implement prototypes to demonstrate data exchange between CAD and manufacturing software.

2002 Develop information models for data exchange between CAD and manufacturing software.

2002 Publish results in appropriate journals, conferences, and workshops.

2000 Gain consensus on acceptability of SIF information model.

2000 Gain consensus on acceptability of above information models and input results of above tasks into ISO TC184/SC4.

2002 Implement prototypes to demonstrate data exchange between traditional CAD and knowledge-based CAD and input results of above into ISO TC184/SC4.

2002 Gain consensus of traditional CAD-augmented CAD interchange format.

Standards & Measurement Services

Committees:

ISO TC184/SC4 standards committee - This projectprovides the technical leader of the WG12 working group on Short-Term and Long-Term Parametrics within the STEP (ISO 10303) standards effort.

Manufacturer's CORBA Interface Testing Toolkit (MCITT)

Leader: Flater, David W.

Total FTE .50

1998 MEL Goals Supported

1. Laboratory research and development

Project Objective

To produce a publicly available software toolkit that supports several kinds of testing (integration, conformance, performance) of manufacturing system software components whose interfaces use the Object Management Group's publicly available specification for software integration, the Common Object Request Broker Architecture (CORBA).

Needs Addressed

Industry, government, and academic institutions working on innovations in manufacturing software need tools to test the behavior of software components within complex distributed systems. Whether it is conformance to a standard that must be verified, or merely interoperability with other components, there is in each case a need for testing tools that can operate within the environment of a complex distributed system and reduce the amount of labor required to verify the behavior of components.

MCITT ("M-kit") is a direct response to a need expressed by industrial partners Honeywell and Advanced Micro Devices working under the auspices of the Advanced Process Control (APC) Framework Initiative (an Advanced Technology Program (ATP)-funded initiative). They had already developed a semi-formal method for specifying the expected behavior of CORBA components, but they lacked the tools to automate the testing of those behaviors. MCITT not only provides those tools, but allows the broader manufacturing community to benefit from the APC testing methodology. Wider use of this technology will result in higher reliability and lower costs for companies using CORBA for their manufacturing systems integration needs.

In addition to supporting the MEL goals listed above, MCITT also serves the broader NIST mission of providing enabling, infrastructural technology to enhance U.S. competitiveness in the global marketplace.

Technical Approach

CORBA supports the construction of distributed systems containing many components. These components can interact in complex ways, not necessarily conforming to a strict client-server model. This generality is necessary to enable many real-world systems to be built on a distributed architecture. However, it is also the reason why testing these systems is so difficult. Because each component can have complex dependencies on any number of other components, it is often impossible to test them in isolation.

MCITT mitigates this problem by minimizing the amount of effort needed to produce simple emulations — test servers — which can be used to replace actual servers in a testing scenario. The person doing the testing only needs to specify the behaviors that are important for the specific scenario being examined, and MCITT will do the rest. CORBA boilerplate code, memory management, and stubs for unused operations are generated automatically.

There are two ways of defining behaviors for MCITT: the procedural way, using Interface Testing Language (ITL), and the declarative way, using Component Interaction Specifications (CISs). CISs are more formal and automated, being the direct realization of the APC testing methodology, whereas ITL gives the tester more direct control over the testing process. By supporting both the procedural and the declarative approaches, MCITT makes itself useful in a wide variety of testing scenarios, including those that are not conveniently described in a formal language.

Server emulation is primarily useful for integration testing and for providing a controlled environment within which to do conformance testing. MCITT provides additional services in support of conformance and performance testing with specialized ITL language constructs: conformance test assertions, automatic inclusion of conformance test boilerplate, and timed loops for performance evaluation. Support for deriving testing assertions from Component Interaction Specifications will be added this year.

MCITT supports information-based measurement. The following informal tests were done in FY 1997 and are also identified in the Framework and APC projects:

- Twelve generic performance, robustness, and scalability tests for APC
- Proof of concept conformance test for the Standard for the Exchange of Product model data (STEP) Part 26 (Standard Data Access Interface (SDAI) / Interface Definition Language (IDL) binding)
- Proof of concept scenarios using Framework Product Data Manager (PDM) and APC Machine interfaces

Related Developments

- The APC Framework Initiative is an ATP-funded project with participation from Honeywell and Advanced Micro Devices. MCITT has been used to provide testing services needed by the APC partners and this will continue in the coming year.
- The code generation capabilities of MCITT were used by the NIST MEL Framework Project to ease the migration of its software components to a newer version of CORBA.
- The NIST MEL Technologies for the Integration of Manufacturing Applications (TIMA) Validation Project will be able to use MCITT to accelerate validation of emerging interface standards. MCITT can significantly reduce the amount of labor required to use a new interface definition in a testing scenario. Also, a proof-of-concept conformance test for STEP Part 26 (SDAI/IDL binding) was already produced.
- Some of the ongoing inter-laboratory Competence Projects, notably the Testability of Interaction-Driven Manufacturing Systems project, could benefit from the APC testing methodology as supported by MCITT.
- The Object Management Group (OMG) is considering issuing standard bindings for scripting languages such as Tcl and JavaScript to implement CORBA clients and (probably) servers. MCITT's ITL shares the goal of providing a simplified procedural method to exercise CORBA interfaces, but it is specialized for testing purposes and translates directly into C++. Use of a scripting language would provide inaccurate results for performance testing of components implemented in C++ (the language of choice in the APC project).
- The Open Group (formerly known as X/Open and the Open Software Foundation (OSF)) has a CORBA validation project that will use Assertion Definition Language (ADL) to do conformance testing on Object Request Brokers (ORBs). It is not clear whether their work could be extended to apply to CORBA interfaces in general, or to what extent the developed technology will be publicly available.

Prior Year Accomplishments

- Created a general overview web page and mailing list.
- Maintained distributions of development iterations.
- Performed proof-of-concept applications of MCITT to STEP Part 26 conformance testing and generation of PDM and APC Machine servers.
- Used MCITT to perform general CORBA performance and robustness testing for APC.

- Assembled and developed the software infrastructure for MCITT and implemented some of the planned functionality.
- Created a web document detailing the original motivation and approach for the project.
- Consulted with industrial partners to determine their requirements and preferences.

FY 1998 Plans

- Use MCITT to support testing of APC Framework components.
- Beta-test MCITT version 0.90.
- Produce user's guide for MCITT.
- Finish implementing most important MCITT functionality, identify areas for possible future work.

Five Year Plan Goals vs. Fiscal Year

1998 Use MCITT for testing the APC Framework. [APC ATP]

1998 Complete initial implementation of MCITT, conduct public beta-test. [NAMT Framework, APC ATP]

1999 Publish MCITT overview paper. [NAMT Framework]

1999 Release version 1.0 of MCITT. [NAMT Framework]

2001 Maintain, distribute, and/or privatize MCITT technology. [NAMT Framework]

Manufacturing Enterprise Integration

Leader: Nell, Jim G.

Staff: Christopher, Neil
New Hire

Total FTE 1.00

1998 MEL Goals Supported

1. Laboratory research and development
3. Information-based National and International Standards and Measurements
5. Customer satisfaction and program recognition

Project Objective

Develop tools, methodologies, and standards for representing manufacturing enterprises to make it easier to create, modify, and combine enterprises.

Needs Addressed

Manufacturing enterprises need ways to improve their infrastructures and processes to enable effective operation in a more agile, virtual-enterprise mode so that enterprises can produce higher-quality products, with better repeatability, lower cycle time, and more customized production capability. Meeting this need involves applying enterprise-integration technologies and integrating business discourse internationally. However, investment in these technologies on a large scale has been slowed by a lack of business justification, a plethora of seemingly conflicting solutions and terminology, and by an insufficient understanding of the technology by the end-user community. Industry, therefore, also needs tools, reference architectures, well-placed standards, and methodology to help develop credible ways to justify integration-related investments.

Technical Approach

Conduct the International Conference on Enterprise Integration and Modeling Technology (ICEIMT'97). Use results of the ICEIMT'97 workshops and conference to create research projects comprising international experts to mitigate issues proposed at the conference. Examples are: a unified enterprise-modeling language, human representation in manufacturing-enterprise models, and defining meaningful relations among lower-level manufacturing applications such as enterprise-resource planning, manufacturing-execution systems, and electronic commerce; and a high-level comprehensive enterprise-reference architecture such as the Generalized Enterprise-Reference Architecture and Methodology (GERAM). Much work is being done on these challenges by consortia around the world. Therefore, this project intends to coordinate the work to the extent that existing groups and groups planning to work a sector of the domain are able to identify what has or is being done so that they can leverage their work.

Plan program of work and convene ISO TC184 SC5 WG1 (Industrial Automation Systems and Integration; Modeling and Architecture); Advance ISO 14258, Rules and Guidelines for Enterprise Models, to International-Standard status; and produce a committee draft of ISO 15704, Requirements for a Generalized Enterprise-Reference Architecture and Methodology.

Develop in WG1 a strategic standardization plan that defines the role of international standards in the field of integration technology; that is, where and where not to apply them. The intent is to create the correct standards that will allow successful implementations without inhibiting freedom of enterprise design and technical innovation.

Related Developments

- The new MEL/MSID "Enterprise Resource Planning Interfaces" project will model manufacturing activities and information flows. The Process-Specification-Language project is seeking a common way to exchange and share manufacturing process information. The NAMT Framework project is implementing, testing and analyzing a vertical slice of manufacturing-enterprise standards from enterprise-resource planning through manufacturing-execution systems to machine control.

Prior Year Accomplishments

- Maintained and Upgraded Standard for the Exchange of Product model data (STEP) on a Page. STEP On A Page (SOAP) is distributed on paper at the SC4 meetings and on the World Wide Web.
- Planned the ICEIMT'97 (International Conference on Enterprise Integration and Modeling Technology), sponsored by NIST and the European Community European Strategic Program for Research in Information Technology (ESPRIT). All preparatory information for this conference and the workshops was distributed entirely on the World Wide Web and an e-mail exploder.
- Began to develop working draft of ISO 15704, Requirements for a generic enterprise-reference architecture and methodology.
- Received international approval to advance committee draft of ISO 14258, Concepts and Rules for Enterprise Models, to final draft international standard (FDIS).
- Convened four ISO TC184 SC5 WG1 meetings. Maintained the World-Wide-Web site for WG1 documents and activities.

FY 1998 Plans

- Organize projects at NIST comprising experts from ICEIMT-97 to develop unified enterprise-modeling language and representing human resources in enterprise models.
- Lead ISO TC 184/SC5/WG1 in work to create a road map for ISO TC 184/SC5/WG1 standards with the domain of enterprise-integration frameworks, enterprise-reference architectures, and enterprise models.
- Convene the ICEIMT'97 conference and follow-on activity.
- Ballot and register ISO CD 14258, Concepts and Rules for Enterprise Models, as an international standard.
- Produce a committee draft of ISO 15704, Requirements for a generic enterprise-reference architecture and methodology.
- Plan program of work and convene TC184 SC5 WG1, Modeling and Architecture.

Five Year Plan Goals vs. Fiscal Year

2000 Develop a unified enterprise modeling language

1998 Develop in WG1 a strategic-standardization plan that defines the role of international standards in the field of integration technology.

1998 Convene International-Conference-for-Enterprise-Integration-Modeling-Technology

1999 Develop a way to represent humans in enterprise models

1999 Plan and conduct ICEIMT'97 follow-on projects

2000 Convene TC184 SC5 WG1; Advance ISO 14258 to International-Standard status, and produce a working draft of ISO 15704 for Requirements for a Generalized Enterprise Reference Architecture and methodology.

2000 Connect lower-level applications to enterprise-level representations such as GERAM

2002 Pilot implementations

2002 Tool development

Standards & Measurement Services

Standards Committees:

Convener of ISO TC184 SC5 WG1 Industrial Automation Systems and Integration; Modeling and Architecture

Manufacturing Resource (MR) Data Representation

Leader: Jurrens, Kevin K.

Staff: Novick, Greg

Total FTE 1.25

1998 MEL Goals Supported

3. Information-based National and International Standards and Measurements

Project Objective

Facilitate standardization and industry implementation of a proposed electronic representation for manufacturing resource (MR) data. Lead efforts for standardization of cutting tool data through Technical Committee 29 Working Group 34 of the International Organization for Standardization (ISO TC29/WG34). Facilitate liaison between ISO technical committees to ensure compatibility and no duplication of effort. Initiate standardization of other types of MR data in addition to cutting tool data.

Needs Addressed

Representations of manufacturing resources (machine tools, cutting tools, etc.) are used within a variety of manufacturing software applications, including software to perform process planning, simulation, tool selection, cost estimation, and machine tool programming. Manufacturing enterprises often rely on multiple software systems, purchased from different vendors, each of which requires access to different representations of the manufacturing resources used by that facility. This situation results in resource data stored and maintained multiple times in multiple formats for different applications within a given facility. This in turn causes much duplicate work for maintaining the information, redundant data stores of MR data which may or may not contain the most recent and accurate information, and longer lead times for implementing new systems that require this data. System integration or sharing of resource data between systems or engineering functions is not possible without information loss in the current environment. The problem is compounded because originating sources of such information (e.g., machine tool and cutting tool manufacturers) do not publish equivalent characterizations of their products in their customer literature. Prior efforts to resolve this problem have typically resulted in company-specific data structures and system implementations that are applicable to only a single application within the organization, with much duplicated effort required to implement systems for other application areas.

A single representation for manufacturing resource information that is common to a variety of software applications and engineering functions would reduce or eliminate these problems. This common representation would shorten product cycle time by enabling system integration and sharing of resource data, reduce software operating costs by eliminating costly maintenance of multiple data stores, lower manufacturing costs through less duplication of effort and more efficient engineering functions, and increase product quality by allowing ready access to the most current and accurate MR data. Common representations of manufacturing resources can also enable the resource vendors to offer documentation of their products via mechanisms consistent with state-of-the-art computing and networking technologies, including integrated databases, CD-ROM disks, on-line services, or electronic vendor updates, and provide capabilities for direct import of vendor MR data into customer applications.

Technical Approach

This project is a continuation of prior efforts carried out under the Advanced Technology

Program (ATP) Rapid Response Manufacturing (RRM) Intramural Project. This work was identified as a primary need by the RRM industry consortium to improve manufacturing system integration capabilities. Much documentation exists for this project and is available through the project web page (http://www.nist.gov/rrm).

The project has addressed a limited scope of MR data representation, including milling and turning machine tools; cutting tools appropriate to the processes of milling, drilling, boring, reaming, tapping, and turning; cutting tool inserts; and the tool holding and assembly components required to mount the cutting tools to the machines. The technical approach has been to develop information models based upon a detailed analysis of MR data requirements from the perspectives of mechanical part manufacturers, manufacturing software providers, and manufacturing resource vendors. The application focus of the project has been on manufacturing cost estimating, manufacturing process planning, and numerically controlled toolpath generation.

Standardization of the proposed MR data structure has been active primarily within the area of cutting tool data. An international standards group has been organized through ISO TC29 (small tools) WG34 (cutting tool data representation and exchange) to create the ISO 13399 series of standards for cutting tool data. Various liaisons have been formed with other ISO standards groups to ensure compatibility of manufacturing data standards. Within the U.S., an advisory group to ISO TC29/WG34 has been formed under the American National Standards Institute/Cemented Carbide Producers Association (ANSI/CCPA) B212 (carbide tooling) standards organization. Standardization of other aspects of the proposed MR data (e.g., machine tools, tool holders) is being pursued through interactions with industry representatives and various standards bodies.

Prior Year Accomplishments

- Developed a detailed requirements specification for MR data (NISTIR 5707). Created EXPRESS and EXPRESS-G information models based on these requirements. Conducted widespread distribution for industry review.
- Developed the MR Data Interface as a web-based demonstration system.
- Submitted the MR Data Requirements Specification and EXPRESS information model as a draft proposal for standardization to ISO TC29 (small tools). Facilitated formation of a new working group (WG34) for standardization of cutting tool data.
- Notified by several industry collaborators of their plans for use and prototype implementation of the proposed MR data representation.
- Transferred results to industry through a Commerce News press release, with further publication in several industry trade publications.
- Published a book chapter titled “Beyond Product Design Data: Data Standards for Manufacturing Resources” in “Rapid Response Manufacturing: Contemporary Methodologies, Tools, and Technologies” (Chapman and Hall).
- Presented two papers on representation of MR data in the Concurrent Engineering session of the 1996 Japan-USA Symposium on Flexible Automation.
- Initiated liaison and collaboration between the ISO TC29/WG34 and ISO TC184/SC4 standards groups to ensure compatibility among respective standards.
- Served as editor of the ISO 13399 standards, with Committee Draft (CD) versions of ISO 13399 Parts 2-4 released for international review.
- Initiated formation of the ANSI/CCPA B212 Advisory Group to develop U.S. positions and contributions for standards related to cutting tool data representation and exchange.

- Served as U.S. representative and technical expert for the ISO TC29/WG34 standards group. Confirmed as chair of the WG34 ad hoc group responsible for developing the content of the ISO 13399 series of standards.
- Submitted a detailed proposal for turning tools data representation to ISO TC29/WG34. The NIST contribution was selected as the baseline WG34 standard.

FY 1998 Plans

- Publish results of MR data efforts in technical journals
- Update capabilities of the MR Data Interface (web-based demonstration system)
- Pursue and facilitate external prototype implementations
- Pursue standardization of other MR data aspects
- Facilitate liaison between ISO TC184 and ISO TC29/WG34
- Participate in the ANSI/CCPA B212 Advisory Group to ISO TC29/WG34
- Lead MR data standardization efforts as chair of the ISO TC29/WG34 ad hoc group

Five Year Plan Goals vs. Fiscal Year

1998 Transfer of leadership to industry

Standards & Measurement Services

Standards Committees:

Project interactions with standards committees:

1. ISO TC29 (small tools) WG34 (cutting tool data representation and exchange)

Development of ISO 13399 standards related to representation and exchange of cutting tool data. This project serves as a key participant on this committee and chairs the ad hoc group tasked with developing the cutting tool hierarchy and detailed data representations.

2. ANSI/CCPA B212 (carbide tooling) Advisory Group to ISO TC29/WG34

Development of U.S. positions, contributions, and consensus viewpoints for issues and proposals raised by the ISO TC29/WG34 committee. This project serves as a key participant on this committee and assists development of U.S. contributions.

3. ISO TC184/SC4 (industrial data)

Development of STEP, Parts Library, and Manufacturing Management Data (MANDATE) standards. This project serves to facilitate liaison(s) between ISO TC184/SC4 and ISO TC29/WG34.

4. ISO TC184/SC1 (physical device control)

Development of standards for computer control of physical devices. This project serves to facilitate liaison between ISO TC184/SC1 and ISO TC29/WG34.

5. ISO TC39 and ANSI/American Society of Mechanical Engineers (ASME) B5 (machine tools)

Development of standards related to machine tools. This project plans interaction with these committees to provide information regarding electronic representation of machine tool data and to attempt to stimulate interest in a machine tool data standardization effort.

Manufacturing Standards Development

Leader: Phillips , Lisa

Staff: Barnard-Feeney, Allison
Gray, Sharon P.
Kemmerer, Sharon J.
Mitchell, Mary
New Hire
Rinaudot, Gaylen
Trager, Ellen

Total FTE 3.70

1998 MEL Goals Supported

3. Information-based National and International Standards and Measurements

Project Objective

To ensure the timely development and approval of integrated manufacturing product data standards that have the quality, integrity, and completeness required to support a broad range of U.S. and worldwide information-driven manufacturing requirements.

Needs Addressed

Growing industrial dependency on the use of computers in design, manufacture, and product support demands frequent sharing of information, and integration of processes across an enterprise. US industry invests $7.4B annually in mechanical designs. Boeing has estimated the lack of effectively implemented product data sharing mechanisms is a $500M problem annually for their company alone. Various process improvements that can shorten lead times, improve quality, and reduce costs depend on standards development and deployment (e.g. representing design intent).

Technical Approach

The focus of this project is the development and enhancement of neutral product data exchange standards within the international standards development community in support of the broad range of these industrial requirements. NIST provides technical and administrative leadership at the national and international level through the associated standards organizations respectively.

National: ANSI IGES/PDES Organization (IPO). The IPO is the ANSI-accredited standards development organization (SDO) responsible for product data standards for US manufacturing. Current standardization efforts include: Product Data Exchange Using STEP (PDES) (ANS US PRO/IPO-200) and the Initial Graphics Exchange Specification (IGES) (ANS US PRO/IPO-100).

International: ISO TC 184/SC4. SC4 is responsible for product data standards other than those directly related to electrical/electronics. Current standardization efforts include: Standard for the Exchange of Product Model Data (STEP) (ISO 10303), the representation of Parts Library information (P-LIB) (ISO 13584), Parametrics (ISO 14959), and a new approach to moving manufacturing management data (MANDATE) (which includes ISO 15531) through the use of EDI.

Related Developments

- Other projects benefiting from this project include the STEP Conformance Testing, the Application Protocol Development Environment, and the Standards RoadMap projects.

Prior Year Accomplishments

- Published the first release of ISO 10303 abstract test suites as Type II Technical Reports for the SC4 community to review and to comprehend the magnitude and benefits of abstract test suties supporting STEP Application Protocols.
- Initiated 37 standards ballots and tallied and resolved 34 ballot results.

- Developed new SC4 home page, enabling WWW access to SOLIS (SC4 Information System On-line) and other SC4-related information.
- Established a convenor approval checklist for ISO 10303 to be used to assist in the qualification of STEP parts. This check list will enable the transition from inspected-in quality to built-in quality which is the fundamental goal of the Quality Committee.
- Published several SC4 Standing documents including, “Guidelines for application interpreted model development”, “Guidelines for the development of mapping tables” and the “Abstract test suite development guidelines”.
- NIST hosted an IPO workshop on product data exchange. The objective of the workshop was to provide a business-based overview of the capabilities of STEP and progress on its successful use by industry. Approximately 125 industry representatives participated.
- The NIST SC4 Secretariat hosted an ISO TC 184/SC4/WG12 workshop to resolve requests for changes to several ISO 10303 standard specifications (parts 41, 43 and 44). Responsiveness to these issues will enable STEP application protocols to progress towards standardization with minimal delay.
- Maintain secretariat for TC184/SC4 (STEP)
- SC4 Online Information Service Updates (SOLIS)

FY 1998 Plans

- Provide Technical Leadership of ISO TC 184/SC4
- Prepare and host qualification process training to cover SC4 standing document directives
- Develop a plan for Quality Committee transition
- Update and publish methods documents including the SC4 supplementary directives, AIC guidelines, AP Development guidelines, Standard Enhancement Discrepancy System procedures document, STEP interpretation documentation, Qualification procedures document, and SC4 Organization handbook.
- Develop a strategic approach for SC4 in the 21st century, and for deploying a procedure for more efficient management of interdependencies between standard parts.
- Develop and deploy a training and outreach program for instituting quality aspects of qualification, interpretation, integration, editing, and conformance testing to the STEP community.
- Develop a master CD-ROM of ISO 10303 for ISO Central Secretariat.
- Develop a web-based approach to administer Standard Enhancement Discrepancy System (SEDS).
- Enhance and maintain a Qualification Resource database for managing the SC4 resources contributing to the quality processes required for producing an ISO and SC4 standard.
- Restructure the private access ftp site to better accommodate the maturing of multiple SC4 standards.
- Develop tools to automate and improve the maintenance of documents on SOLIS; provide a workshop to introduce technologies being employed by the Secretariat, and solicit feedback.
- Participate in developing US PRO workshop to identify US priorities and requirements for industrial data standards development.
- Prepare a final draft manuscript recording the development and implementation of STEP for publication as a NIST special publication.

Five Year Plan Goals vs. Fiscal Year

1998 Provide Technical Leadership of ISO TC 184/SC4

1998 Provide and support an international repository and configuration management site for digital product standards and supporting developmental documentation for ISO TC184/SC4

1998 Provide Secretariat Support for ISO TC184/SC4

1998 Provide metrics for interpretation

1998 Develop procedures, select collaboration technology, and obtain partners to develop standards through virtual interactions

1998 Upgrade standards development tools to reflect technology improvements

1999 Support revision management and additional capabilities for pre-standardization collaborative development

1999 Issue implementation guidelines for IGES to STEP migration

1999 Contribute to SC4 integration, incorporating SC4 architecture elements

2000 Conduct a demonstration pilot on developing standards via virtual interactions

2001 Integrate relevant functional standards into evolving SC4 standards architecture and issue implementation guidelines describing how they can work together

2001 Begin renewal process for STEP initial release, incorporating SC4 architecture enhancements in these editions

Standards & Measurement Services

Standards Committees:

ANSI IGES/PDES Organization (IPO), ISO TC 184/SC4. SC4 is responsible for product data standards other than those directly related to electrical/electronics.

NAMT Virtual Machine Tool

Leader: Jones, Albert T.

Staff: Frechette, Simon P.
Iuliano, Michael
Lee, Yung-Tsun Tina

Total FTE .55

1998 MEL Goals Supported

1. Laboratory research and development
2. Physical-based National and International Systems of Standards and Measurements

Project Objective

This project is being conducted as part of the National Advanced Manufacturing Testbed (NAMT) “Development of Machine Tool Performance Models and a Machine Data Repository” project. The main goal of the project is the development of a virtual environment containing the software applications needed to simulate the machining of a part. That environment will contain information models that represent performance characteristics and error maps of actual machines, and simulation tools to simulate the execution of Numerical Control (NC) programs on those machines.

Needs Addressed

First article prototyping is still a common practice in manufacturing today. Parts are manufactured and inspected to verify conformance to the design specifications. Based upon verification results, the design and/or manufacturing plans are modified and the process is repeated. Several iterations may be required before the part is committed for final production. This is costly, time consuming, and wastes valuable resources. It is required because existing software tools do not predict the outcome of the manufacturing and inspection processes accurately. Inaccuracies are due to the fact that the machine and process models that are used in the software are imprecise. They do not capture the performance and behavior of their real counterparts.

Furthermore, there are no provisions in the current standards for performance and behavior information. Significant cost and time savings could be achieved if these standards were in place and used to create more accurate simulation models.

Technical Approach

The Manufacturing Systems Integration Division is working with the Automated Production Technologies Division to create simulation models for the representation of the performance and behavior of various machine tools. In addition, the two divisions are working together to develop information models for both the inputs and the outputs for those simulation models. The inputs consist of a representation of the machine tool itself and its error maps. The output consists of the resulting part geometry and surface finish. The input models will be used to drive several commercial simulation products that are commonly used to model machine tools and coordinated measuring machines. The outputs will be compared to the outputs from real machines. The initial testing will be done on machine tools available at NIST. Additional testing will be done at collaborator sites.

Related Developments

Mallet Technology & Microcompatibles Incorporated made modifications to their simulation software to incorporate machine tool error models and visualize the results.

Prior Year Accomplishments

- Developed an Express model based on draft document that specifies Performance Evaluation Data for the 2nd NAMT Machine Repository Workshop.
- Developed a complete packet that is used to demonstrate the feasibility of using EXPRESS for exchanging the ball bar performance evaluation data.

- Developed C language software that manipulates the analysis results from both simulations and generates two data files that are used to visualize machining errors using Pro Engineer.
- Developed two kinematic motion simulations of Monarch Metalist machining center.
- Developed Computer-aided Design (CAD) solid model of the Monarch Metalist Machining Center in Pro Engineer.

FY 1998 Plans

- Hold year-end WEB-based demonstrations using those models
- Complete development of EXPRESS models for performance data

Five Year Plan Goals vs. Fiscal Year

1998 Develop information models for ball bar data

1999 Complete interoperability tests for ball bar data

2000 Develop information models for B5 data. ISO TC 184/SC4, ANSI/ASME B5.54, ISO 230 Parts 1-5.

2001 Complete interoperability tests for B5 data

National Industrial Information Infrastructure Protocols (NIIIP)

Leader: Morris, Katherine C.

Staff: Algeo, Mary Beth
Denno, Peter O.
Garguilo, John J.
Sauder, David A.

Total FTE 1.60

1998 MEL Goals Supported

3. Information-based National and International Standards and Measurements

Project Objective

To collaborate closely with industrial partners in fostering the development and deployment of technology and standards enabling industrial virtual enterprises. To foster the adoption of STEP (STEP is the familiar name for ISO 10303 the Standard for the Exchange of Product Model Data) in the operation of industrial virtual enterprises. To track the development efforts of the Advance Technology Program (ATP)-funded NIIIP Solutions for MES-Adaptable Replicable Technology (NIIIP SMART, MES stands for Manufacturing Execution Systems) project for potential future collaborations. To support Defense Advanced Research Projects Agency (DARPA) as the Contracting Officer's Technical Representatives (COTR) for the NIIIP Affordable Missile Manufacturing Pilot—Linking Enterprises (AMMPLE) project, to explore the subject of supply chain integration in order to identify additional research and collaborative priorities for NIST.

Needs Addressed

The NIIIP Consortium is developing open-industry software protocols that will make it possible for manufacturers and their suppliers to effectively interoperate as if they were part of the same enterprise, even though many of these interactions are unscheduled and occur between both sophisticated and relatively unsophisticated users who utilize a wide range of computer systems, operating environments, and business processes. The core competencies that MSID contributes to NIIIP are expertise in the areas of STEP technology and standards and, more generally, expertise in manufacturing, testing, standardization, and integration technology and architectures. NIST works with NIIIP in several project areas including the initial NIIIP TRP project, the ATP-funded NIIIP SMART project, and the DARPA-sponsored NIIIP AMMPLE project. Under the initial TRP effort, NIST has applied its expertise to the development of a set of protocols to support access to product data by a virtual enterprise in which partners are geographically distributed, to facilitate the adoption of those protocols by formal standards organizations (OMG and ISO), to the definition and documentation of the NIIIP Reference Architecture, and to the formulation of a testing strategy for NIIIP. Under the SMART project NIST has further worked with NIIIP in deploying NIIIP technology to the domain of manufacturing execution system integration and in tailoring a standards architecture and scenarios suitable for that environment. In the more recent AMMPLE effort NIST expertise in manufacturing has driven the project to consider a wide industrial segment in evaluating the solutions for supply chain integration.

Technical Approach

For the TRP effort the NIIIP Consortium uses a spiral development methodology to deliver three iterations of a) a reference architecture, b) toolkits which are the building blocks of an instantiated reference architecture, c) research prototypes, and d) pilot demonstrations. In the development of these deliverables NIIIP adopts and converges existing standards and technology from STEP, the Object Management Group (OMG, a consortium of software vendors), the Internet Society, and the Workflow Management Coalition. The consortium's efforts beyond these are focused on deploying the technology to various industrial sectors including missile manufacturing supply chains, ship building industry, and the manufacturing execution systems marketplace.

The technical research of the NIST project has involved the integration of STEP technology and standards with object-oriented technology and standards emerging from OMG, the issues surrounding the standardization of interfaces for product data management and the integration of MES, as well as the issues revolving around supply chain management. Additionally, NIST has begun to formulate a methodology for the testing of such interfaces.

NIST is providing direction for and implementation of components of a toolkit to bind the Standard Data Access Interface (ISO 10303 Part 22, a.k.a. SDAI) to OMG standards for distributed computing. The development of this capability is key to the NIIIP goal of providing data sharing and STEP information modeling in the context of a NIIIP industrial virtual enterprise.

Related Developments

- The development of products supporting the OMG standards provides a basis for distribution of key components of NIIIP including the NIIIP STEP toolkit. More recent activities are investigating Java combined with the World Wide Web (WWW) as an alternate means for distribution. Related projects include NIIIP SMART and NIIIP AMMPLE.
- SDAI (ISO 10303: part 22) has been promoted to an international standard; two language bindings (C++ and IDL, OMG's Interface Definition Language) are currently undergoing balloting as Draft International Standards (DIS) documents. This project has served to validate all of these standards.
- NIIIP AMMPLE is one of three DARPA Affordable Multi-Missile Manufacturing (AM3) projects that focus on the development and deployment of tools and technologies to enable efficient supply chain integration in the missile sector. These three efforts are separate yet complementary. Using NIIIP Lite technologies, AMMPLE will enable the establishment of virtual enterprises between missile primes and their suppliers with a focus on bid management processes for engineered parts. The Supply-Chain Technologies for Affordable Missile Products (STAMP) project, led by the South Carolina Research Authority (SCRA), targets key enablers of an integrated product team. These include tools for managing product data, coordinating workflow, negotiating and resolving design issues, and ensuring data security and integrity within the supply chain. Science Applications International Corporation (SAIC) leads the third effort, the Missile Industry Supply-Chain Technology Initiative (MISTI). It centers on a unified approach for discovering and accessing commodity and engineered parts, products, and processes on standard Web pages that are both human and machine interpretable.

Prior Year Accomplishments

- Scenario development for the three signed missile prime contractors began:
  - For Lockheed Martin Vought Systems (LMVS), the prime perspective is complete and work continues to develop the supplier perspective with Boeing NA.
  - Raytheon Electronic Systems (RES) and Raytheon/TI Systems (RTIS) have established a common scope. The specification of the prime and supplier perspectives continues.
- NIIIP Lite University, sponsored by NIIIP to introduce missile prime contractors and select suppliers to NIIIP Lite technologies. Participants agreed to jointly develop an electronic procurement tool for DOD mis-

sile contractors and their suppliers.

- AMMPLE cooperative agreements between NIST and NIIIP, and between NIIIP and three missile prime contractors (LMVS, RES, and RTIS) signed. Draft paper "State-of-the-Art Assessment of Integrated Supply Chain Management"(SOTA) written.
- Developed CORBA distributed object interfaces that provide task sequencing to the Enhanced Machine Controller.
- Constructed STEP physical files of cutting tools and components based on the Manufacturing Resource model (MR) and information from vendor catalogs. The work validates usability of the MR model.
- Developed an information mapping capability and language based on current work in the SC4 EXPRESS-X Mapping Language New Work Item. The mapping populates objects from information in database form.
- Provided a strawman Product Data Manager Interface Definition Language interface as a input to a collaborative proposal from NIIIP to the Object Management Group (OMG) for interfaces to access Product Data Management systems.
- Provided briefings to SMART investigators describing the SIMA/NAMT, virtual workcell, and its current capabilities and interfaces.
- With NIIIP partners, published in IEEE Internet Computing "Data Protocols for the Industrial Virtual Enterprise", Feb 97.
- Developed ATP report "Integratable Manufacturing Execution Systems: Experience and Perspective." (October 1996)
- Published and presented paper "Opportunities and Challenges of the STEP Product Data Facility" at DH Brown Symposium on Product Information Management and at Rensselaer Polytechnic Institute's Electronics Agile Manufacturing Research Institute (EAMRI) Conference on Agile and Intelligent Manufacturing Systems. (October 1996)
- Participated in consortium demonstrations for each of the TRP cycles.
- Iteratively developed and demonstrated in NIIIP Cycles 1, 2, and 3 a STEP Product Data Facility (SPDF) which exercised data exchange capabilities based on STEP and distributed computing capabilities using OMG standards. (September 1995, June 1996, and August 1997, respectively.) Results of these prototypes were incorporated into STEP's Data Access Interface C++ and IDL language bindings. The resulting software prototypes a STEP Product Data Facility which accesses an object-oriented database (Object Store) and is accessible in a distributed environment through an Object Request Broker (ORB, Orbix).

FY 1998 Plans

- Deployment of NIIIP Lite technologies per AMMPLE scenarios: - deploy first Bid Management System VES to missile prime contractors (January 98) - deploy revised BMS VES (April/May)
- Continued scenario development with prime missile contractors and select suppliers.
- Publication of a "State-of-the-Art Assessment of Integrated Supply Chain Management."

- Track the ATP-funded SMART and EECOMS (Extended Enterprise Coalition for Integrated Collaborative Manufacturing Systems) projects for potential collaboration next year.
- Contribute to the end-of-project documentation of the NIIIP Reference Architecture: describe an approach to validation of NIIIP Protocols, describe the STEP Data Access Interface including a description in the Unified Modeling Language (UML), and document requirements for the reference architecture.

Standards & Measurement Services

Standards Committees:

ISO TC184/SC4/WG11; OMG's Domain Task Force on Manufacturing Systems

NIST Identifier Collaboration Service

Leader Libes, Donald

Total FTE 0.25

1998 MEL Goals Supported

1. Laboratory research and development
5. Customer satisfaction and program recognition

Project Objective

The NIST Identifier Collaboration Service (NICS) is a service to encourage collaboration among researchers and developers when choosing identifiers, far in advance of when it might ordinarily occur. This supports and enhances de facto and nominal standard-development activities and software development and reuse.

Needs Addressed

Choosing identifiers collaboratively enables easier and faster development of standards and reuse of software. Use of this system would provide immediate and significant time and cost-savings to NIST as well as millions of software and standards developers worldwide. Industry needs the benefits of this service but no single company wants to fund it - this project would benefit many while only the original company pays for it. In contrast, NIST, as a neutral site, is the ideal sponsor for the NICS. Unlike the traditional standards activities performed by NIST, the NICS is complementary. In particular, NIST performs research for standards and participates in the creation of standards. More and more, standards are growing increasingly complex. Many standards are taking 5 or even 10 years to complete. In part, this is because the technology and in some cases even the standards themselves are being created by many people without collaboration. Without giving up competitive advantages, these people want to collaborate yet they lack the mechanisms to do so in the area that the NICS addresses.

Technical Approach

The project is establishing, promulgating, and supporting an automated World Wide Web-based service. Anonymous browsing is permitted. Authentication is performed on all data additions or modifications. Registration and all day-to-day operations will eventually be automated. The service will be entirely implemented via CGI (Common Gateway Interface) programs using technology already developed within MEL. Backend services are provided by a high-performance database. The NICS will be self-maintaining and future costs will be limited to minimal operational expenses such as electricity and hardware support.

Related Developments

- There are a number of technologies and standards that are related to the NICS such as ANSI (American National Standards Institute) 11179/ISO X3L8. These must be explored for leverage and/or alignment. In addition, related efforts such as thesauri management address similar problems but with radically different focus. It is essential that we understand the work going on in these other fields.
- As this is a Web-based project, related developments in the technology underlying Web-based delivery will undoubtedly impact this work.

Prior Year Accomplishments

- Version 1 of a world-wide registry for identifier information. This includes an experimental but functional publicly available NICS with several populated domains.

FY 1998 Plans

- Initial population of selected domains.
- Document the NICS design and rationale in order to feed results back to other standards representatives as well as build awareness and spur use.
- Document the NICS implementation for the purpose of subsequent support as well as promulgating lessons learned.
- Research and possibly participate in developing standards concerning identifier and data-element registration.

Five Year Plan Goals vs. Fiscal Year

1999 Secondary population

2001 Policy definition and documentation

2002 Standards compliance

2002 Documentation

1999 Programmatic interfaces

1999 Archiving

2000 Hierarchical namespaces

2002 Explore java enhancements

2002 Domain-specific knowledge and interface

2002 Document experiences

The NIST Manufacturing Collaboratory

Leader: Steves, Michelle P.

Staff: Knutilla, Amy
Wu, Daniel

Total FTE 2

1998 MEL Goals Supported

1. Laboratory research and development

5. Customer satisfaction and program recognition

Project Objective

The NIST Manufacturing Collaboratory ("collaborative laboratory" [see National Collaboratories, National Academy Press, 1993]) will ultimately enable individuals and groups of manufacturing researchers to tap into, as well as contribute to, the collective knowledge regarding advanced manufacturing research and standards in a coherent, unencumbered fashion.

Needs Addressed

Engineering research and development efforts continue to become increasingly multidisciplinary, and often involve participants in distant locations. Manufacturing enterprises themselves are also becoming more distributed in order to best compete in the world marketplace. All of these activities necessarily require collaboration, yet the mechanisms supporting this collaboration are generally still old-fashioned (blueprints, telephone, etc). With the increasing pace of innovation, introduction, and delivery of new products, American industry cannot afford to ignore the advantages offered by computer-assisted collaboratory technology. This project serves the manufacturing community by applying and demonstrating various developments in collaboratory technology in the context of specific manufacturing applications.

Technical Approach

In the current climate of compressed product lifecycles and competitive marketing windows, it is vital for NIST to become quickly proficient with collaboratory techniques. This both serves to amplify NIST's own research and standardization effectiveness and prepares NIST to be ready with standards and technology solutions as American industry adopts collaboration technology. To be in this position very quickly, a team including NIST, the University of Michigan, and manufacturing partners is being pursued. This initial team offers immediate access to state-of-the-art expertise in collaboratory technology through the University of Michigan, plus willing industrial partners with an interest in this technology. This project makes it possible for NIST to deploy a cutting edge manufacturing collaboratory in a neutral environment in which industrial and government partners can cooperate and learn, and in which NIST can begin the active development work necessary to support the next generation of standards for using collaboration technology to support manufacturing. Within NIST, the Manufacturing Extension Program (MEP) has indicated strong interest in the NIST collaboratory both as a testbed for pilot projects with small manufacturing enterprises (SMEs) in the MEP network and as an infrastructure for remote deployment of technology products and services.

In order to quickly reach a significant level of effort in the area of manufacturing collaboratory technology, a strategy of leveraging several sources of funding is underway. For example, it is important that each party have a stake in the success of the manufacturing collaboratory testbed project. Initially, at NIST, the Systems Integration for Manufacturing Applications (SIMA)program and the Advanced Technology Program (ATP) are supporting this effort. The FY98 project plan calls for a functional requirements analysis for the manufacturing research and operations domains, deployment of a pilot implementation of a manufacturing collaboratory based on the requirements analysis, and an analysis of the collaborative effectiveness of the pilot implementation. Throughout these major phases of the project, the University of Michigan, with its collaboration technology experience, and our industrial partners, with their "real-world" manufacturing requirements will play key roles in establishing the NIST manufacturing collaboratory as a premier manufacturing collaboration testbed, which will serve as a technology environment to implement and assess the effects of distributed, integrated manufacturing.

As the project demonstrates results, the plan is to involve NIST, the NAMT program, the National Science Foundation (NSF), Defense Advanced Research Projects Agency (DARPA), and the State of Michigan in funding collaboratory development.

Related Developments

- In general, the Internet has become more ubiquitous in the American workplace and the workplace culture is beginning to support and demand interactions and collaborations in virtual space. In particular, the implementation of higher-bandwidth wide-area networks, emerging supporting standards such as multimedia teleconferencing standards (H.320), and ground-breaking work in the area of knowledge acquisition and retrieval are all contributing factors to a successful collaboratory implementation. Also, other research programs are making strides in this area such as the Department of Energy (DOE) 2000, University of Sydney, and the DARPA Intelligent Collaboration and Visualization (IVC) program.

Prior Year Accomplishments

- Acquired, deployed and demonstrated collaboration tools
- Prepared white paper that described the NIST manufacturing collaboratory concept and proposed an implementation strategy

FY 1998 Plans

- Analyze and document collaborative effectiveness
- Deploy pilot manufacturing collaboratory - demonstration, training and documentation
- Identify, analyze and document the functional requirements for the manufacturing domain

Five Year Plan Goals vs. Fiscal Year

1998 Deploy pilot manufacturing collaboratory.

1998 Compile functional requirements of collaboration in the manufacturing research and operations domains

1998 Deploy prototype of virtual environment interface supporting CMC

2000 Provide training on collaborative environment use

2000 Analyze effectiveness of collaborative environment

2002 Implement pilot manufacturing knowledge base

Ontologies for Integration

Leader: Schlenoff, Craig I.
Staff: Denno, Peter O.
Libes, Donald

Total FTE .85

1998 MEL Goals Supported

1. Laboratory research and development.

Project Objective

The objective of this intramural work is to move closer to the ultimate goal of seamless system integration by using the principles behind ontological engineering to provide and capture unambiguous definitions of manufacturing concepts. The output of this work will be a manufacturing taxonomy with formal definitions of exactly what each term/concept means and how they interrelate. This shared understanding will provide a common "manufacturing view" of concepts and terms which would facilitate the integration of manufacturing applications and systems that function towards a common goal.

Needs Addressed

A major challenge facing industry today is the lack of interoperability between heterogeneous systems. In the last decade, there has been an increase in the number and types of software applications that attempt to capture and manipulate manufacturing information. As manufacturing companies move toward increased integration, there is a growing need to share this information. The costly effort required to integrate these applications is a significant obstacle to creating more agile manufacturing companies. Several recent industry roadmaps and agendas underscore this need for manufacturing systems integration. Among these were publications produced by The National Research Council, The National Electronics Manufacturing Initiative, The National Center for Manufacturing Sciences, The Semiconductor Industry Association, and the Semiconductor Research Corporation.

Current manufacturing system integration efforts are usually based solely on how information is represented (the syntax or terminology) without a formal description of what the information means (the semantics). With the growing complexity of manufacturing information and the increasing need to completely and correctly exchange information among different manufacturing systems, the need for precise and unambiguous capture of the meaning of concepts within a given system is becoming apparent. Ontologies provide a mechanism which one can provide and capture a semantic underpinning for specifications supporting manufacturing systems integration. The field of ontological engineering has shown to be a proven and reliable tool for capturing definitions of concepts in a variety of domains outside of manufacturing. By using these principles in the manufacturing domain to unambiguously specify the meaning of concepts, integration between these manufacturing systems can be greatly facilitated by focusing on what a concept means instead of the particular term that is used to represent it.

In addition, research in this area could help redefine and improve the methodology for standards development. Basing future standard development efforts on formally defined semantics will not only erase any possible ambiguity within the standard but will also allow for interoperability among standards since ontologies are software and language (syntax) independent.

Technical Approach

The approach for this proposed project begins with an analysis of current ontological systems and efforts to determine which can be used or leveraged to model concepts in the manufacturing domain. Examples of ontological systems include Cyc, the Ontolingua server, and the Unified Medical Language System (UMLS). Once an appropriate system is chosen, the project will move to identifying and defining semantic concepts in a variety of manufacturing domains, strongly leveraging existing projects within the Manufacturing Systems Integration Division. These concepts will then be modeled in the chosen ontological system by first modeling the concepts in a single domain (keeping track of the modeling issues and how they were resolved) and then modeling the remaining domains using the lessons learned. The result at this point will be a set of disjoint, domain-specific ontologies. As this modeling progresses, it is fully expected that there will be conflicting definitions of the same term in different domains. For example, a "resource" in one domain may be completely different than a "resource" in another domain. This being the case, the project will then perform an analysis to help identify inconsistencies in the use of terms among various domains (semantic mismatches) as well as help to establish a means to generalize these terms to a level that is common among the domains in question. This will allow these various domain-specific ontologies to be merged. The output of this work will be a taxonomy of terms and concepts along with formal definitions of exactly what each of those terms/concepts mean and how they interrelate. Although it would be impossible to create a complete taxonomy of every interpretation of every term, a high-level, extensible subset of this taxonomy will be created to serve as a basis for future, domain-specific additions and specializations.

Related Developments

- Examples of ontological systems include Cyc, the Ontolingua server, and the Unified Medical Language System (UMLS). The Defense Advanced Research Projects Agency (DARPA)-funded Process Interchange Format (PIF) project, the NIST Process Specification Language (PSL) project, and the Advanced Research Projects Agency (ARPA)/ROME Planning Initiative (ARPI) Shared Planning and Activity Representation (SPAR) project are developing ontologies to enable the exchange of process and plan information.

Prior Year Accomplishments

- Wrote a white paper describing the role of semantics and ontologies in manufacturing system integration
- Explored the feasibility of applying the principles behind ontological engineering to manufacturing systems integration

FY 1998 Plans

- Publish the first version of a paper documenting the ontological system survey
- Perform a survey of existing ontological systems to determine their strengths and weakness compared to the representation of manufacturing semantic concepts

Five Year Plan Goals vs. Fiscal Year

1999 Research existing ontological efforts

1999 Populate the manufacturing ontology

1999 Identify and define domain-specific concepts

2000 Develop the manufacturing taxonomy

2000 Analyze the manufacturing ontology

Postdoctoral Research in the Engineering Design Technologies Group

Leader: Schwabacher, Mark

Staff: Angster, Scott
Nederbragt, Walter W.

Total FTE 2.50

1998 MEL Goals Supported

1. Laboratory research and development

Project Objective

To conduct research and development of technologies for engineering design, and to concurrently develop data and interface standards, as well as shared product and process models to support the utilization and integration of these systems for design applications.

Needs Addressed

Traditional computer-aided design (CAD) tools focus primarily on the representation of geometry. Tools and methodologies to support other activities within the design process are at a far less mature stage of development. Postdoctoral research in engineering design technology is focusing on several aspects of design with the intent to develop new approaches to supporting design activities using existing and novel technology.

Technical Approach

There are a number of ongoing postdoctoral research activities in the area of engineering design technology. In the current stages of investigation, these projects are being pursued individually. The various components of the engineering design technologies thrust are described below. However, it should be noted that a key emphasis of the long-term development strategy is to create the infrastructure for integration of these approaches through the development of standard data representations and interfaces, as well as shared models and knowledge bases.

Project Component 1: Artificial Intelligence (AI) Augmented Design Optimization (M. Schwabacher)

Manufacturers of complex mechanical systems such as aircraft and automobiles could benefit tremendously from the ability to create better designs faster. Automated optimization promises to rapidly produce better designs. Currently, many manufacturers use "legacy" analysis codes to analyze their designs. It is difficult to use these legacy codes inside of an automated optimization system, but it is not practical to replace the legacy codes with new codes. This research attempts to build a system that automatically optimizes complex engineering designs. This is achieved by augmenting optimization using machine learning and other artificial intelligence (AI) techniques, in order to allow the optimizer to deal with the limitations of the legacy analysis codes.

Project Component 2: An Investigation of the Use of Agent Technologies for Engineering Design (M. Schwabacher)

A large number of researchers have recently applied the name "agent" to a wide variety of technologies. People in the engineering design community need to understand the relationships among these technologies, and how they apply to engineering design. First, this project component seeks to survey these technologies and develop taxonomies of definitions of the word "agent" and of agent technologies and architectures. Second, this project component seeks to explore how these technologies can be applied individually or jointly, to engineering design.

Project Component 3: Interoperability and Data Exchange Issues in the Analysis of Electro-Mechanical Assemblies. (S. Angster)

The emergence of high-performance computing has opened up new avenues for the design and analysis community. Integrated Product/Process Design techniques are allowing multi-functional teams to optimize simultaneously the design of a product. These techniques can be inhibited, however, due to software integration and data exchange issues. This research focuses on these issues as they relate to the design and analysis of electro-mechanical assemblies. One aspect of this work is the creation of an open environment, called the Open Assembly Design Environment, or OpenADE, to allow otherwise disjoint assembly analysis systems to work together using one comprehensive set of data. This work will focus on the design and realization of the architecture, including the development of standard interfaces for assembly applications, data exchange mechanisms for interoperability, and data storage mechanisms for archiving data.

Project Component 4: Improve Interoperability Between Design and Process Planning (W. Nederbragt)

Experienced designers often are able to create successful designs because of their knowledge of manufacturing practices. However, for less experienced designers it is often advantageous to the designer to get input from experienced personnel in the manufacturing sector. Ideally, the designer should be able to get manufacturing or process planning input at all stages of design to aid in the design process. This research aims to enhance interoperability between the design environment and process-planning environment in order to facilitate the creation of new capabilities. To improve communication between the two environments, a unified communication scheme is being developed to allow all relevant data to be transferred between both domains. This scheme includes such things as geometry, design rationale, material, and process information.

Prior Year Accomplishments

- Published several journal articles, conference papers, and NIST Internal Reports (Multiple Project Components).
- Identified industrial scenarios for testing prototype (Project Component 3).
- Initial architecture defined (Project Component 3).
- Identified the CAD/Design for Assembly (DFA)/Virtual Reality (VR) toolset for the prototype architecture (Project Component 3).

FY 1998 Plans

- Where applicable, write conference papers, journal articles, and NIST Internal Reports (Multiple project components)
- Develop prototype implementations and application to engineering design problems (Multiple project components)
- Where applicable, establish additional industry collaborations (Multiple project components)
- Develop taxonomy of design/manufacturing objects to represent the information that needs to be exchanged. This requires analysis of existing taxonomies in both design and manufacturing to indicate the types of information that needs to be communicated. (Project Component 4)
- Survey current methods and technologies used in design and process planning. This includes conceptual design tools, detailed design tools, cost estimation systems, and process planning systems. (Project Component 4)
- Demonstration of prototype using Industrial Scenarios (Project Component 3)
- Full realization of the prototype open architecture (Project Component 3)
- Obtain two or more agent framework systems and select a particular engineering design problem to use as a test case (Project component 2)

- Extend existing AI-augmented optimization system to use active learning, background knowledge in the machine learning, and additional rules in the rule-based gradients (Project component 1)

Five Year Plan Goals vs. Fiscal Year

1999 Document results and integrate technology into other MSID research

Process Specification Language (PSL)

Leader: Schlenoff, Craig I.

Staff: Knutilla, Amy
Libes, Donald

Total FTE .9

1998 MEL Goals Supported

1. Laboratory research and development.
5. Customer satisfaction and program recognition

Project Objective

The objective of this project is to identify or create a process representation that is common to all manufacturing applications, generic enough to be decoupled from any given application, and robust enough to be able to represent process information for any given application. This representation would facilitate process information sharing among various applications because they would all "speak the same language", either as a second language or their native language. This project is designed specifically to promote outreach and consensus through activities such as the establishment of electronic discussion lists, active industry review and feedback, and on-line project status through the World Wide Web.

Needs Addressed

In the last decade, there has been an increase in the number and types of software applications for manufacturing which attempt to capture the essence of process. These range from tools that simply portray processes graphically to tools that enable simulation, analysis, and/or control of processes. As manufacturing companies move toward increased integration, there is a growing need to share process information. Several recent industry roadmaps and agendas, including the National ResearchCouncil's Manufacturing Studies Board and the National Electronics Manufacturing Initiative, underscore the need for standard, formal process representation to enable integration of manufacturing process applications. Adoption of a standard process specification language by process software vendors will ease the job of systems integrators, reduce the cost of integration for manufacturers, and increase the market for commercial software vendors, especially in the small and medium sized manufacturing sector. On a broader scale, the use of this technology will allow more rapid response of American manufacturers to changing product and market needs, which will let them remain competitive while responding to these changes.

Technical Approach

The approach taken for the project has been to break it into distinct phases, each coupled with on-going outreach and consensus efforts to promote the establishment of a widely-accepted standard. The first phase, completed in FY96, defines requirements for specifying process from a broad range of manufacturing business and engineering applications. On-going research results were maintained on the World Wide Web (http://www.nist.gov/psl/), with feedback incorporated into the set of requirements. The second phase, representation analysis, helped to determine how well existing representations support the requirements found in phase 1. An on-line matrix was used to gather input from the geographically dispersed members of the community who are supporting the PSL effort. This analysis provided an objective basis for developing a comprehensive language and promotes the leveraging of existing work. This in-depth understanding of the many existing approaches to representing process provided further definition of what was required to exchange process information: a process specification that is developed for exchange must have an unambiguous set of semantic terms. The identification and definition of the semantic concepts inherent to manufacturing processes became the focus of the third phase of the project. The semantic-concepts will then be mapped to multiple existing presentations (e.g., Petri nets, Unified Modeling Language (UML), etc.). In addition, the third phase will include the identification/determination of suitable manufacturing scenarios that will, among other things, help to advance the development of the PSL semantic concepts while keeping the project grounded in real-world situations. The output of this phase will be a very scaled down version of the final PSL that will be used in a series of pilot implementations (phase four of the project). These pilot implementations will help to identify areas in which the specification language should grow and ensure the language's completeness and ease-of-use. It is this validated, documented language that will be submitted to appropriate organizations as a candidate international standard. Feedback and consensus from the process community will be and has been aggressively pursued during all phases of the project.

Related Developments

- The PSL project is closely aligned with the Defense Advanced Research Projects Agency (DARPA)-funded Process Interchange Format (PIF) project, which focuses on the exchange of process information for business applications (e.g. workflow). Aspects of the PSL are being incorporated in DARPA's Shared Planning and Activity Representation (SPAR) Initiative, whose goal is to create a shared plan representation suitable for use in the Advanced Research Projects Agency (ARPA)-Rome planning Initiative (ARPI) community. Also, the PSL team is working closely with EPFL (Swiss Federal Institute of Technology at Lausanne) which is developing an enhanced Petri Net representation partially based on the findings of PSL.

Prior Year Accomplishments

- Continued making efficient use of Internet-based mechanisms for reporting on-going research and soliciting feedback, generating growing interest in and collaboration with the PSL project. (http://www.nist.gov/psl/)
- Published "Using Process Requirements as the Basis for the Creation and Evaluation of Process Ontologies for Enterprise Modeling" in ACM SIGGROUP Bulletin Special Issue of Enterprise Modeling;
- "Requirements for Modeling Manufacturing Processes: A New Perspective" in the Proceedings of the DETC'97: 1997 Design Engineering Technical Conference;
- "Proceedings of the First Process Specification Language (PSL) Roundtable" as NIST Internal Report (NISTIR) 6081,
- "Requirements for Modeling Manufacturing Processes" in the Proceedings of "Intelligent Systems: A Semiotic Perspective" Conference.
- Developed a strong collaboration with the DARPA-funded Process Interchange Format (PIF) project that resulted in a common semantic "core" for both projects. This helped to strengthen the supposition that the specification of process at its highest levels is the same, independent of the domain of interest.
- Identified and defined a set of semantic primitive concepts for specifying manufacturing processes. This small set of concepts will be the basis from which all future process-related concepts will be defined.
- Held a two-day PSL Roundtable at NIST, preceded by a "virtual", electronic discussion, attended by twenty carefully selected experts in the process representation community. The technical conclusions arrived at during the dynamic meeting set the direction for future PSL efforts. There was much interest among the participants to see this effort progress and almost all agreed to serve on task forces to help further different aspects of the language.

- Analyzed twenty-six existing process representations with respect to the process information requirements found in the first phase of the project with the assistance of over 20 geographically-dispersed industry and academic experts. This seamless collaboration was accomplished, in part, through the use of a web-based on-line matrix developed in-house. The results of this analysis helped to show, among other things, the necessity for an unambiguous set of semantic concepts to underlie the Process Specification Language.

FY 1998 Plans

- Publish NISTIR: Description of pre-release PSL and lessons learned in its development
- Publish NISTIR: Process Specification Language: An Analysis of Existing Representations
- Sponsor a second PSL roundtable with key vendors and researchers to aid in identifying additional semantic concepts that will increase the robustness of the Process Specification Language.
- Perform at least one pilot implementation to help identify concepts that are needed in the PSL which do not currently exist. This pilot implementation will exchange process information between two manufacturing applications using PSL as the interlingua for the exchange.
- Develop pre-release PSL that will constitute of small subset of the pre-defined semantic concepts that will be mapped to two or more presentations in the context of a simple manufacturing scenario.

Five Year Plan Goals vs. Fiscal Year

1998 Create mappings to presentations

1998 Identify/Define semantic concepts

1998 Develop pre-release PSL

1998 Develop/Identify appropriate scenarios

1999 Validate PSL Prototype

2001 Build Consensus/Tech Transfer

2001 Initiate Standardization

Production and Product Data Management

Leader: McLean, Charles R.

Staff: Barber, Martin Ivor
Barkmeyer, Edward J.
Bartolotta, Anna
Iuliano, Michael
Jones, Albert T.
Kroon, Auke Jan
Lecapitaine, Christophe M
Lee, Yung-Tsun Tina
Leong, Swee K.
Ling, Z. K.
Riddick, Frank H.
Thomas, David Wynn
Umeda, Shigeki

Total FTE 4.95

1998 MEL Goals Supported

1. Laboratory research and development
3. Information-based National and International Standards and Measurements

Project Objective

The overall goal of the project is to address integration problems associated with production engineering, scheduling, and simulation systems. The project will develop process models, information models, and interface specifications, databases, and extensions to commercial production software which resolve or facilitate systems integration.

Needs Addressed

The worldwide market for Computer-aided design/Computer-aided manufacturing/Computer-aided engineering (CAD/CAM/CAE) software applications increased by more than 5% to $16.5 billion dollars in 1993. The computer professional services business which includes systems integrators is expected to grow considerably in the coming years. The growth of the systems integration portion of the computer professional services business is highly dependent upon the growth of the CAD/CAM and CAE software market because data exchange formats and interface protocols between CAD/CAM/CAE software applications are incompatible. This incompatibility results in an increased business for professional integrators who create custom integration solutions to support data exchange between software applications. These solutions are expensive to implement, require a great deal of time to develop, are very inflexible, and lack the incorporation of standards. These custom solutions result in numerous problems that can be broken down into three major technical impediments: 1) the lack of understanding of what information and knowledge is required between design, planning, and production areas, 2) the lack of information exchange standards that support both product and process data exchange between applications, and 3) the lack of interface standards which define interface protocols between applications. This project addresses this problem in the area of production engineering and production scheduling systems and interface standards.

Technical Approach

The project will assess industry needs, with respect to production engineering, production scheduling, and systems integration. The project will select and install commercial software applications that are used to engineer production systems, perform production scheduling, and simulate production. The project will define requirements, develop information and process models, specify application architectures, interfaces, and databases for integrating production software systems. Prototype integrated systems will be constructed from commercial products. The principal elements of the technical approach are: 1) Identify and address critical industrial needs through collaboration, 2) Develop solutions to production software integration problems, 3) Construct prototype environments using commercial products, 4) Validate results through industrial testing of system implementations, 5) Specify and promote needed industry standards, and 6) Facilitate the rapid commercialization of new technology.

Related Developments

ISO TC 184/SC4 AP 227, ISO SC4 WG8, ISO STEP 213, and ISO TC 184/SC4, especially ISO 10303, Parts 213 and227, and the work of WG8.

Prior Year Accomplishments

- Completed Phase II Requirements Analysis document for Assembly Process Specification
- Modified Quest models to use an external routing file, an internal transfer agent, & machine families.
- Closed the loop between the status database and AutoSched.
- Completed analysis of various schedulers and simulators that describe the different views of work orders, routings, schedules, and dispatch lists.
- Defined and implemented basic Common Object Request Broker Architecture (CORBA) Interface Definition Language (IDL) interfaces between the Deneb Quest simulator and the Visual Basic (VB) Status Manager and between the Deneb Quest Simulator and the Java-based Dispatcher.
- Defined preliminary CORBA IDL interfaces between each of the components of the scheduling toolkit.
- Developed a Product Data Management (PDM) Business Object Model for Computer-aided Manufacturing
- Participated in development of two “initial proposals” to the Object Management Group (OMG) for standard interfaces to PDM systems and was a member of the OMG PDM proposal evaluation team.
- Held joint OMG/SC4 workshop on PDM standards and created formal liaison between OMG and SC4.
- Contributed to the development of manufacturing scenarios for the Defense Advance Research Projects Agency (DARPA) Affordable Multi-Missle Manufactory (AM3) project.
- Completed demonstration of the interface between a part assembly system and Deneb IGRIP simulation for several miter saw line assembly stations
- Completed Phase I Initial Manufacturing Exchange Specification (IMES) Problem statement/industrial need document for production management
- Completed Phase I IMES Problem statement/industrial need document for production system engineering.
- Completed simulation models for shops at AMP and B.F. Goodrich.
- Completed Phase II Requirements Analysis document for Plant Layout
- Completed scheduling models for these shops using data provided by collaborators.
- Completed Phase II Requirements Analysis document for Process Plan File Format
- Completed production system engineering decision model
- Defined preliminary architecture for virtual supply chain management system
- Published Jones, A., McLean, C., Leong, S., “A Virtual Production Testbed”, Proceedings of WCSS’97, Singapore, September 1997
- Published Umeda, S. and Jones A., “Virtual Supply Chain Management: A Re-engineering Approach Using Discrete Event Simulation”, Proceedings of the World Conference SCI’97, Caracas Venezuela, July 1997
- Published Umeda, S. and Jones, A., “Simulation in Japan: State-of-the-Art Update”, NISTIR 6040, July, 1997.
- Published Iuliano, M., Jones, A., and Feng, S., “Analysis of AP213 for Usage as a Process Plan Exchange Format”, NISTIR 5992, March 1997.

- Published Jones, A., and McLean, C., "Production Management Standards: Industrial Need", NISTIR 6058, September 1997.
- Published Iuliano, M., "The Role of Product Data Management in the Manufacturing Engineering Toolkit", NISTIR 6042, August 1997.
- Published Riddick, F. and Loreau, A., "Models for Integrating Scheduling and Shop Floor Data Collection Systems", Proceedings of the IASTED MIC'97 Conference, Innsbruck, Austria, March 1997
- Published Riddick, F., "Using Quest as a Proxy for a Real Shop Floor and Data Collection System", Proceedings of Deneb Users' Conference, September 1997.
- Published McLean, C., and Leong, S., "Industrial Need: Production System Engineering Integration Standards NISTIR 6019, June 1997
- Completed Phase II IMES Requirements Analysis document for shop floor status

FY 1998 Plans

- Publish 3 papers in International conferences.
- Conduct demonstrations showing the integration of simulation tools using JAVA, Virtual Reality Modeling Language (VRML), and CORBA.
- Conduct WEB-based demonstration of virtual supply chain
- Hold meetings with industrial partners to review specifications.
- Establish a neutral production resource simulation model library using VRML and JAVA (or other formats as appropriate).
- Complete Phase II and Phase III IMES documents for discrete event simulation, shop orders, and routings
- Complete Phase III IMES documents for shop floor status, plant layout, assembly process and machining process plan specification.
- Complete Phase I document for supply chain management project.
- Participate in final reviews and recommendations for the OMG PDM Enablers proposal, the STEP "PDM Schema", and AP 232.
- Continue support of ongoing South Carolina Research Authority (SCRA) STAMP and OMG activities.
- Define requirements and information models for production simulation system performance metrics.
- Define discrete event simulation objects and a neutral interface to discrete event simulation software.
- Develop production system engineering software toolkit.

Five Year Plan Goals vs. Fiscal Year

1998 Specify interface for assembly process specification and routing simulations.

1999 Define generic machine model interface for simulation.

2000 Expand production management models to include additional data Manufacturing Resource Planning (MRP).

2001 Specify model for manufacturing production line performance evaluation.

2001 Specify problem solving language for production system engineering.

Standards & Measurement Services

Standards Committees:

Object Management Group (OMG), ISO TC 184/SC4.

Robust Model-based Optimal Control of Manufacturing Processes

Leader: Ivester, Rob

Total FTE 1.00

1998 MEL Goals Supported

1. Laboratory research and development

Project Objective

Develop a generalized robust optimal control methodology to enhance production quality and efficiency.

Needs Addressed

American machine tool companies are facing a strategically difficult time now due to overseas competition. Improving quality and efficiency will enable them to maintain a foothold in this extremely competitive marketplace. A novel control methodology shows great promise for allowing control in the presence of uncertainty in the modeled system.

Technical Approach

This methodology will be based on Recursive Constraint Bounding (RCB), an Adaptive Control Optimization (ACO) method recently developed by Dr. Ivester that takes advantage of available models while compensating for their uncertainty.

Related Developments

- Applications are being pursued for Hard Turning, Drilling, High-Speed Milling, and the Hexapod.

Prior Year Accomplishments

- Core algorithms and pilot implementation of the enhanced recursive constraint bounding methodology.

FY 1998 Plans

- Computer-based service for exporting empirically calibrated analytical models of manufacturing processes. This service will enable other manufacturing activities to leverage process characterization information obtained directly from specific manufacturing stations or machines.
- Prototype application of control system based on Recursive Constraint Bounding technology.

Five Year Plan Goals vs. Fiscal Year

1998 Produce and deliver a prototype application of control system based on Recursive Constraint Bounding technology.

1998 Produce and deliver a computer-based service for exporting empirically calibrated analytical models of manufacturing processes. This service will enable other manufacturing activities to leverage process characterization information obtained directly from specific manufacturing stations or machines.

Standards Roadmap

Leader: Nell, Jim G.

Staff: Christopher, Neil

Total FTE: .50

1998 MEL Goals Supported

1. Laboratory research and development
4. Internal Management.
5. Customer satisfaction and program recognition

Project Objective

(1) Develop criteria for MSID to use in strategic planning of standards development activities. (2) Create a standards-information resource that includes standards and sources of standards information as well as categories that represent Manufacturing enterprise-integration-related-standards domain, purpose of the standard, and the status of standard development. (3)Prepare a Standards Road Map to summarize findings, recommend relevant standards categories, and recommend levels of support for MSID.

Needs Addressed

Standards development is expensive because it is a labor-intensive process. In the information-technology domain the standards-development process is additionally costly because many elements of the technology are developed concomitantly with the standards. With limited resources, NIST needs to be able to choose which standards activities to support and how much support is appropriate by using some criteria that rank the various standards developments with respect to their value to the MSID and, ultimately, to MSID's customers.

Technical Approach

Define the domain, relevant to MSID, of enterprise-integration-related standards, stating which standards to include and which to exclude. Enterprise-integration-related standards are those, at any level in the enterprise, that help processes to interoperate. Assume, however, that the project will consider only those standards in the information-technology domain. The project will create an information resource that will enable MSID management to identify standards activities that, if supported, will help MSID better serve its customers' information-standards needs. This resource will be a database, a Web site, a paper document, or a combination to be determined. The project will develop criteria to indicate which standards are most important and to what level those important standards should be supported. Finally, the project will prepare a standards road map to enable MSID to form a better standardization strategy.

If practical, analyze the various standards approaches; for example, Object Management Group (OMG), ISO, proprietary, National Industrial Information Infrastructure Protocols (NIIIP); and base conclusions on MSID customer needs over the next five years. Include three levels of criteria: setting priorities and measuring results at NIST, relevance for MSID involvement, and does/could NIST use the standard

Related Developments

- The MSID is engaged in strategic planning. The Standards Road Map Project provides a reference and criteria for setting strategic direction of MSID's involvement in development of standards for manufacturing information systems.

Prior Year Accomplishments

- Defined the domain, relevant to MSID, of enterprise-integration-related standards, stating what is to be included and what is to be excluded in division standards participation. Determined which categories of standards, domains and subdomains, that MSID considers relevant. Developed the criteria to allow MSID to determine whether or not MSID should assign resources to support the standards activity.

FY 1998 Plans

- Complete Standards Road Map Document including recommendations for its use.
- Populate the database with information supplied by MSID groups.
- Design and build the information-resource/database.

Five Year Plan Goals vs. Fiscal Year

1998 Create a standards-information resource to include a list of sources and/or the standards by category that represents enterprise-integration-related-standards domain, purpose of the standard, and the status of standard development

1998 Prepare a Standards Road Map to summarize findings, recommend relevant standards categories, and recommend levels of MSID support

STEP Conformance and Interoperability Testing

Leader: Frechette, Simon P.

Staff: Barnard-Feeney, Allison
Denno, Peter O.
Mitchell, Mary
Rinaudot, Gaylen

Total FTE 1.60

1998 MEL Goals Supported

3. Information-based National and International Standards and Measurements

Project Objective

Provide an objective means of evaluating the ability of design, engineering, and manufacturing systems to meet Standards for the Exchange of Product Model Data (STEP) requirements, thereby accelerating the adoption of this international standard; provide interoperability testing and tools for STEP over the Internet to users, thereby improving translator quality and decreasing translator time-to-market; and develop a generalized approach for rapidly developing conformance and interoperability testing tools and test specifications from formal integrated manufacturing specifications. Provide a basis for international acceptance of STEP-compliant products developed by U.S. vendors.

Needs Addressed

The need for standardized representations of product information that are suitable for electronic communication between engineering and manufacturing functions is growing. A single international standard, ISO 10303 Product data representation and exchange — commonly referred to as STEP (STandard for the Exchange of Product model data), has been designed to meet this need. The STEP standard is seen by many as the means by which multiple tiers of a supply chain can communicate evolving technical descriptions of products. Mid-level suppliers are caught between customers demanding specific data formats and small suppliers capable of providing one data format only . As the number of different, proprietary formats increases, the cost of maintaining systems and translators increases geometrically. A number of questions must be answered, however, before industry can be expected to adopt the STEP standard. When will implementations of STEP be production ready? Are commercial systems STEP compliant? How can implementation be tested? This project is addressing these and other similar questions by developing tools and methodologies that can provide a level of confidence required for production use. New technologies and applications using those technologies must demonstrate capabilities at least equivalent to current methods.

Technical Approach

Provide a means by which STEP products can be objectively measured against the standard. A set of value-added software tools is being developed for use by vendors and users during product development and for interoperability trials. The tools are extensible to accommodate the expanding series of STEP Application Protocols (AP). This has resulted in a modular system with two major elements: a test system that integrates various testing tools and administers the actual tests, and a set of tools for generating test suites. Our approach includes providing such services over the Internet which offers many advantages over traditional testing methods. Vendors can gain confidence in their product's conformance with the standard, and along with users, vendors can extend the testing for interoperability objectives. In both uses, many of the same tools can be employed. The current focus is on better integration of tools and enhancements to ease extensibility and interoperability testing.

Two additional approaches are also being employed. The first is to leverage early implementation experience to validate the test system and test suites. NIST and the Industrial Technology Institute (ITI) have formed alliances with US STEP pilots of PDES, Inc. and the Automotive Industry Action Group, as well as a vendor round-table. A beta-testing program is continuing to further ensure the utility of this testing capability. The second is to pursue an infrastructure for dissemination of information on STEP conformance and interoperability activities, including an efficient US based conformance testing program that is appropriate for industry requirements. Participation in the international standards effort related to conformance testing is required to make sure US industry and vendors of STEP products have equal access to the world market.

In terms of interoperability testing, NIST will provide software toolkits and develop metrics to support the data exchange and analysis of implementations using the STEP standard. NIST will provide expertise in STEP methods and testing. NIST will act as a neutral participant and provide a neutral testbed site to establish communications infrastructure. Under this project, NIST STEP toolkits will be upgraded in response to user needs. These toolkits will be freely available to the public and NIST will provide network access so users can interactively use the toolkits without the effort of installing and maintaining the software locally. This project is leveraging work ongoing in industry.

Prior Year Accomplishments

- Enhanced NIST-ITI Test System (NITS) available on the Internet. The on-line test system provides a mechanism for early testing and validation of STEP applications. STEP AP 203 and 202 tests are available.
- Completed beta AP203 conformance testing for two major Computer Aided Design (CAD) system vendors.
- Published Abstract Test Suite (ATS) Guidelines. This document (ISO TC184/SC4 N434), defines the approved methods for developing the artifacts used in the conformance testing of a STEP application protocol.
- Completed draft international standard ISO 10303-34: Abstract Test Methods.
- Completed and submitted Initial Implementors Agreement on AP203 Class 1 (configuration management) for consideration as a Technical Report. This agreement will provide a basis for certification of STEP AP203-compliant applications.
- Completed Initial Working Draft of ISO 10303-35: Abstract Test Methods for Implementations of the Standard Data Access Interface (SDAI). SDAI provides an alternative to file-based information exchange.
- Enhanced NIST STEP Class Library for multiple-schema support. The NIST STEP Class Library is used to develop STEP testing tools.
- Completed AP202 (drawings) Rule Validator covering Conformance Classes 1,5, and 9. The rule validator has proven to be a critical tool for testing implementations of STEP translators. Vendors report significant timesavings resulting from the use of the AP203 rule validator in identifying and resolving errors.
- Completed draft international standard Abstract Test Suites (ATS) 303 and ATS 302. ATSs provide a method for documenting conformance test requirements.
- Released enhanced Application Reference Model (ARM)-Application Interpreted Model (AIM) Browser/Editor (AABE) software for use in creating test cases for AP 203 and AP202.
- Released enhanced AP203 Rule Validator covering Conformance Classes 1, 2, 5, and 6 for checking the validity of STEP exchange files.
- Supported industry implementation pilot programs — AutoSTEP, STEPnet and PDMnet.

FY 1998 Plans

- Continue support for AutoSTEP, STEPnet and PDMnet and Complete Beta conformance testing activity for AP203 CAD products.
- Support ISO TC184 SC4 Conformance Testing Committee Activities. Edit, maintain and manage submission of STEP Part 34 through the standards process to become Draft International Standard (DIS). Edit, maintain and manage submission of STEP Part 35 through the standards process to become a Committee Draft (CD).
- Provide enhancements and support of existing Abstract Test Suite tools. This will include AE/Application Interpreted Model (AIM) Test Purpose Generator, Application Reference Model (ARM) to Application Interpreted Model (AIM) Browser, Reference Path Generator, Coverage Analyzer, and STEP File Checker. Enhancements will include aligning tools with the latest versions of methods documents including Supplementary Directives, ATS Guidelines, and Mapping Table Development Guidelines.
- Develop Semantic Analyzer for AP203 geometry classes (geometry checker). Currently, the test system checks only structure and agreement. The test system is not capable of determining whether or not part model geometry conforms to test specifications.
- Develop Structure Checking Methodology Extensible to Multiple Application Protocols. This task will address the problem of performing part 21 structural checking for multiple APs and assessing conformance when the application context of the sending AP is different than the receiving AP. The structural checking is most efficiently done by reusing checking algorithms for integrated resource parts and then initiating work to support the specific needs of the emerging APs.
- Form industry review board.

Five Year Plan Goals vs. Fiscal Year

1999 Enhance the STEP testing harness to accommodate the interoperability testing process including the automation of recording, reporting, and the use of automated test tools.

1999 Develop usage test tools to aid interoperability testing (e.g., geometry checker)

2000 Initiate US STEP conformance and certification testing program. Identify US certification body. Accredit testing laboratory(s). Form industry review board.

2002 Continue support for PDES, Inc. interoperability activities and other STEP implementation pilots.

2002 Refine and maintain tools for the development of Abstract Test Suites

2002 Maintain Standards. Edit, maintain and transition STEP Part 34, Part 35, and Part 32.

2002 Extend ATS 302/303 and develop additional test suites as needed by industry.

2002 Participate in formation of international STEP conformance and certification testing program within ISO.

Standards & Measurement Services

Standards Committees:

ISO TC184/SC4 Industrial automation in systems integration, Industrial data subcommittee

Supply-Chain Technologies for Affordable Missile Products (STAMP)

Leader: Leong, Swee K.

Total FTE .10

1998 MEL Goals Supported

1. Laboratory research and development.

Project Objective

The STAMP program will directly impact two Affordable Multi-Missile Manufacturing Program (AM3) objectives: to lower cost and reduce cycle time. The STAMP program focus is the development of Integrated Product Teams (IPTs) formed to respond to a bid to design and manufacture a missile seeker. The program will develop innovative technologies to accomplish the following: link Product Data Management (PDM) systems using data standards, ensure the secure transfer of unclassified proprietary product data, provide low-cost solutions for IPT access through the Internet, improve affordability by involving suppliers earlier in the design process, increase communications throughout the supply chain, and allow earlier and more effective IPT design negotiations.

Needs Addressed

Integrating suppliers into Integrated Product Teams (IPTs) is essential, because these organizations account for more than 50% of the missile weapon system and major subsystem production costs. The STAMP program will significantly improve the collaboration of missile prime contractors and their suppliers, thus enabling dramatic reduction in missile development cost and time to market. By enabling Internet-based IPT collaboration, STAMP will bring the expertise of lower-tier suppliers to the missile development effort earlier in the process. STAMP tools will enable negotiation and resolution of technical issues among team members and provide a common interface between various Product Data Management (PDM) systems. This will improve the ability of IPTs to perform, thus reducing design and production costs.

IPTs are sometimes costly to form, and expertise from the lower tier suppliers is often not available to the design team until late in the design cycle. Barriers that currently exist to discourage effective IPT formation include widely different technological capabilities of suppliers. At one end of the spectrum is a supplier with sophisticated PDM and workflow management systems in place. At the other end of the spectrum is a small supplier that may have only one Personal Computer (PC) at its disposal and no formal PDM or workflow management system. STAMP will demonstrate a user-friendly, low-cost solution that will enable the exchange of technical product data across such diverse environments in a secure manner. This will allow companies from each tier of the supply chain to contribute their expertise early in the product design phase. The STAMP solution will make use of international data standards, the Internet, and will be readily available throughout all levels of the supply chain.

Technical Approach

The STAMP team is comprised of the following teams and member companies:
Customers: Defense Advanced Research Projects Agency (DARPA) Army Aviation and Missile Command (AMCOM)

Program Management: South Carolina Research Authority (SCRA)

Requirements/Validation Team: Lockheed Martin Advanced Technology Laboratory (ATL), Raytheon, Lockheed Martin Infrared Imaging System (IRIS), ELCAN Optical Technologies, Boeing North American, National Institute of Standards & Technologies (NIST).

Development Team: International Business Machines (IBM), Industrial Technology Institute-Michigan (ITI)-Ohio, Integrated Support Systems (ISS)

Implementation Support Team: Arthur D. Little (ADL), SCRA

Technology Transfer Team: IBM, ITI-Ohio

The Requirements/Validation Team is comprised of members from the missile manufacturing community. NIST and these team members provided the activity model, as-is and to-be business scenarios which were used in the development of the STAMP Technical Development Plan and the STAMP Security Policy documents. The Development Team is actively coding the STAMP software modules, while the Implementation Support Team is providing technical management, software integration, and testing. The Technology Transfer Team is pursuing commercialization activities. The program is periodically presented for review during Affordable Multi-Missile Manufacturing Program (AM3) Electronic Interface (EI) Team meetings, which results in valuable feedback from both the EI team members and from AMCOM.

The STAMP technical approach targets key enablers of an IPT. The primary focus is tools for managing and exchanging product data. To further support the IPT, the demonstration will support coordinating the workflow, establishing a communication link over the Internet for negotiating and resolving design issues, and ensuring data security and integrity with the supply chain interaction. The STAMP team will ensure affordability by providing access to client servers and Product Data Management (PDM) systems for IPT capabilities using low-end computer resources. The proposed solution is both flexible and extensible, and builds on industry standards for sharing product data electronically. There are five key requirements that drive the development approach:

1. The IPT is distributed, with the lower-tier suppliers being small- to medium-sized companies.
2. A multi-tier IPT across the supplier chain requires clear, traceable communications of issues and requirements. The environment will provide for real-time issue tracking and resolution.
3. Communications and associated product data will be secure and meet (at a minimum) the primes' and major suppliers' requirements for security. (Excluding classified data)
4. The solution must utilize public communications channels to keep cost of deployment and operations low. (i.e., the Internet).
5. The IPT systems used in development of concepts, design, and manufacture will be different, requiring mediation of product data and strong communication throughout the supply chain.

Related Developments

- Missile Industry Supply Chain Technology Initiatives (MISTI).
- ISO TC 184/SC4 committee work relating to ISO 10303-203 (Application protocol: Configuration controlled design) and ISO 10303-232 (Application protocol: Technical data packaging core information and exchange).

Prior Year Accomplishments

- Completed web-based AP 232 viewer.
- Completed the STAMP program interim report in November, 1997
- Completed the STAMP annual program review and a joint technology demonstration with the Missile Industry Supply-Chain Technology Initiative (MISTI) in September, 1997.
- Completed preliminary STAMP software modules include Negotiation Facility, security mechanisms, and PDM to AP232 data translation

- Completed the STAMP software requirements specification document
- Completed the STAMP system architecture
- Developed a detailed Integrated Product Team security policy guidelines
- Defined a referenced generic missile development process for the missile industry
- Defined a detailed demonstration scenario based on the missile seeker design
- Completed mapping of 3 PDM systems to STEP AP 232.
- Completed the STAMP program Technical Development Plan

FY 1998 Plans

- Demonstrate final design.
- Integrate STAMP software modules.
- Extend security modules.
- Develop commercialization plan
- Implement security plan at multiple IPT locations
- Install STAMP servers and software modules at multiple IPT locations
- Complete the STAMP system architecture

Five Year Plan Goals vs. Fiscal Year

1998 Final Reports

1998 Demonstrate system

1998 Install STAMP server on-site

1998 Integrate software modules.

1999 Commercialization phase.

1999 STAMP Phase II

Standards & Measurement Services

Standards Committees:

- ISO TC 184/SC4, 10303 Part 203
- ISO TC 184/SC4, 10303 Part 232

Systems Integration for Manufacturing Applications (SIMA) Program

Leader: Fowler, James E.

Staff: Johnson, Clarence
New Hire

Total FTE 2.85

1998 MEL Goals Supported

1. Laboratory research and development
4. Internal Management:
5. Customer satisfaction and program recognition

Project Objective

NIST's SIMA Program is the agency's coordinating focus for its Computing, Information, and Communications (formerly referred to as High Performance Computing and Communications, i.e., HPCC) activities addressing the information interface needs of the U.S. manufacturing community. With technical activities in all of NIST's laboratories covering a broad spectrum of engineering and manufacturing domains, the SIMA Program is working to make information interpretable among systems and people within and across networked enterprises. Specifically, the SIMA Program works with U.S. industry to develop information exchange and interface protocol standard solutions to manufacturing integration problems, establish test mechanisms for validating solutions and implementations, and transfer information technology solutions to manufacturing enterprises.

Needs Addressed

The U.S. government's HPCC Program was formally established by the High Performance Computing Act of 1991 (Public Law 102-194). The HPCC Program was augmented in FY94 with a new component known as Information Infrastructure Technology and Applications (IITA). The IITA component supports research and development efforts that will enable integration of critical information systems and demonstrate feasible solutions to problems of national importance. Twenty-first century manufacturing, i.e., advanced manufacturing processes and products, is one of the challenges to be addressed by IITA activities. In FY97, the HPCC Program became Computing, Information and Communications while reorganizing the original elements into Program Component Areas (PCAs). These PCAs build on the foundations established previously and continue to address the HPCC challenge problems. The PCAs are known as High End Computing and Computation, Large-Scale Networking, High Confidence Systems, Human-Centered Systems, and Human Resources, Education, and Training. The Human Centered Systems (HuCS) PCA - which evolved from the IITA component - performs research and development making the products of computing systems and communication networks more easily accessible and usable to a wide range of user communities. Information interface issues are central to such research and development efforts.

The SIMA Program's results will allow manufacturing industries to make use of the National Information Infrastructure (NII) as a mechanism for communicating product and process data among various manufacturing activities such as product/process design, analysis, planning, scheduling, production, and quality control. Manufacturing applications require standard protocols for data exchange (information interfaces) to communicate with each other via NII technologies. The development of information interfaces between the communications infrastructure and manufacturing applications, between different manufacturing applications, and between these applications and their users will improve integration and thereby usability of these systems.

Technical Approach

The SIMA Program has three major elements: manufacturing systems, standards development, and testbeds/technology transfer.

The manufacturing systems element focuses on development of interface specifications for advanced manufacturing systems. Manufacturing applications being targeted by SIMA projects include design, planning, scheduling, process modeling, shop control, simulation, inspection, assembly, and machining. The integration and interface technologies being applied include networking, database technologies, frameworks, and protocols for data exchange. SIMA projects span the industrial manufacturing domains of mechanical products, electronics, and construction.

The standards development element focuses on the application of NIST expertise to assist industry in implementing voluntary consensus standards relevant to computer integrated manufacturing. Successful implementation of manufacturing standards requires validation, pilots, and formal testing to ensure that the standards meet the intended requirements. To this end, SIMA projects work on deployment of standards testing methods utilizing HPCC technologies and participate in industry efforts to take advantage of HPCC technologies enabling pilot implementations.

The testbeds and technology transfer element focuses on establishment of testbeds that both serve the infrastructure needs of laboratory projects and can be used as demonstration sites for collaborative tests between SIMA projects and their industrial partners. In addition to these testbed facilities, technology transfer efforts focus on development of infrastructure technologies specialized to disseminate manufacturing information using HPCC techniques.

SIMA-funded projects at NIST are as follows: Electronic Commerce of Component Information (EEEL), Design/Process Planning Integration (MEL), Enterprise Resource Planning Interfaces (MEL), Information Protocols for Design (MEL), Internet Commerce for Manufacturing (EEEL), Framework (MEL), Operator Interfaces for Virtual and Distributed Manufacturing (MEL), Production and Product Data Management (MEL), Reference Model Architecture (MEL), STEP for the Process Plant Industry (BFRL), Supply Chain Integration (MEL), Process Specification Language (MEL), Virtual Environments and Visualization for Manufacturing (ITL), Application Protocol Development Environment (MEL), STEP Conformance and Interoperability Testing (MEL), Web-based Testing Service (MEL), Advanced Manufacturing Systems and Networking Testbed (MEL), Analysis Tools for Assessment and Optimization of Product and Process Design (ITL), Computerized Access to Full Structural Crystallographic Data (MSEL), Data Model for Molecular Recognition Database (CSTL), Green's Function Library for Advanced Materials Applications with Internet Access (MSEL), Handbook of Atomic Wavelengths for Spectral Lines (PL), Integration of NIST Standard Reference Data into Information Networks (PL), NIST Informatics Web Site Supporting Advanced Ceramics Applications (MSEL), NIST Manufacturing Collaboratory (MEL), Online Access to NIST Chemical Reference Data (CSTL), Standards for Exchange of Instrument Data and NIST Chemical Reference Data (CSTL), Technology Outreach (MEL), Virtual NAMT (MEL)

Related Developments

- The MEL National Advanced Manufacturing Testbed (NAMT) Program leverages experience, results, and facilities developed through the SIMA Program. The Defense Advanced Research Projects Agency (DARPA) program on National Industrial Information Infrastructure Protocols (NIIIP) develops virtual enterprise architectural component interface specifications which are closely linked to those being validated in the SIMA Program. The Department of Energy's Technologies Enabling Agile Manufacturing (TEAM) program's effort to specify and deploy machine controller interfaces bears on architectural developments ongoing in the SIMA Program. Several SIMA projects are jointly funded with DARPA or Navy Programs thereby leveraging each sponsor's results.

Prior Year Accomplishments

- Program accomplishments are detailed under specific SIMA technical projects. Selected programmatic highlights include:
  - Published Technical Program Plan Update
  - Published Annual Program Report
  - Coordinated MEL plans for Next Generation Internet applications
  - Provided annual review of program activities and accomplishments
  - Enhanced SIMA web site for dissemination of Program and project information
  - Demonstrated simulation-based system for illustrating engineering and manufacturing specifications under development

FY 1998 Plans

- Economic Study Assessing Impact of Interoperability Problems in the Automotive Supply Chain
- Integration Technology Tutorial Workshops
  - SIMA project plans are included under specific SIMA technical project descriptions. Program activities will continue to ensure that the technical efforts of SIMA funded projects provide standards-based solutions to manufacturing system integration problems.

Five Year Plan Goals vs. Fiscal Year

2002 Publish annual report summarizing program's previous year's accomplishments.

2002 Provide annual review of program activities and accomplishments

Technology Outreach

Leader: McLean, Charles R.

Staff: Iuliano, Michael
Krishnamurthy, Rangan

Total FTE .55

1998 MEL Goals Supported

5. Customer satisfaction and program recognition

Project Objective

Develop a virtual manufacturing demonstration which can be used to illustrate the integration and standardization activities underway within the Systems Integration for Manufacturing Applications (SIMA) Manufacturing System Environment projects. The demonstration will be based on a constructed virtual model of a manufacturing system which highlights the different project activities, systems, data, interface specifications and standards required to integrate manufacturing design, planning and production systems. The model will also explain how SIMA is leveraging outside resources in the development of standards specifications.

Needs Addressed

This project will allow SIMA Management to effectively convey the integration work underway in the SIMA project to potential collaborators, sponsors, academia, and supporters from industry and government. The demonstration and virtual manufacturing model will be designed to illustrate the physical and informational components of the integration work in the SIMA project. The demonstration will be scripted to allow different SIMA managers and staff to deliver the demonstration. Demonstrations can be tailored to satisfy different target audiences' interests. This will allow better understanding of SIMA projects', goals, and objectives.

Technical Approach

Use Simulation software, Hyper-Text Markup Language (HTML), JAVA, and the Virtual Reality Modeling Language (VRML) to construct a virtual model of a manufacturing system. The manufacturing context of the model will be a combination of a conventional machine shop and a high volume assembly line producing consumer products. Various machined parts and machining stations will be used as test data and test cases for the machine shop portion of the model. The assembly line portion of the model will be based on the Black and Decker mitre saw. Test parts and data will be based on different mitre saw components and sub-assemblies. The virtual model will be augmented with a narration script. A user will be able to navigate the virtual model to investigate various aspects of the data contained within the virtual manufacturing system.

Prior Year Accomplishments

- Published Paper "Development of Manufacturing Systems Models Using Virtual Reality Modeling Language". K. Kasthurirangan , M. Iuliano, C. Mclean. NIST 6093 Nov 1997.
- Developed a 15 minute narrated demonstration using seven VRML worlds that was presented during the SIMA program review July 97.

FY 1998 Plans

- Prepare a paper to present at the Design of Information Infrastructure Systems for Manufacturing (DIISM) conference May 98, Texas.
- Develop a new VRML world based on SIMA projects and status to be presented at the SIMA program review summer 98.
- Develop a world wide web site that contains the seven VRML worlds with audio clips of the narration embedded in the worlds.

- Develop a world wide web site to display two-dimensional images from the seven VRML worlds along with the associated narration text.
- Prepare a narrated Powerpoint presentation with audio to be demonstrated at the 1997 AUTOFACT conference in Detroit November 1997.

Five Year Plan Goals vs. Fiscal Year

1998 Develop external web site with 2-D pages and 3-D VRML worlds.

1998 Create a new VRML model illustrating integration modeling techniques

2002 Incorporate new SIMA data, interfaces and status into virtual manufacturing models 98-2002

2002 Create new VRML models, access mechanisms, and web pages based on SIMA Program deliverables.

Testability of Interaction-driven Manufacturing Systems

Leader: Fowler, James E.

Staff: Garguilo, John J.
Knutilla, Amy
Kuhn, D. Richard (ITL)
Libes, Donald
Rosenthal, Lynne S. (ITL)

Total FTE 1.95

1998 MEL Goals Supported

1. Laboratory research and development

Project Objective

This project will investigate, evaluate, adapt, and apply advanced techniques for testing the implementations of complex information specifications which are the basis for increasing numbers of engineering activities and manufacturing systems. In addition, the project also seeks to identify mechanisms for building "testability" into evolving information specifications.

Needs Addressed

Increasingly, manufacturing systems and the standards for them define complex interactions among system elements. The non-sequential processing designs of newer manufacturing systems have interacting elements which make it more complex to determine if a system is responding appropriately. Current testing methods expect to evaluate for a known response to a predetermined set of inputs. Evaluating an electronic message to determine if it contains a valid recipient is an example of a simple static test. For complex manufacturing systems, the only means of evaluation is through a standard interface but the tightly coupled interactions of the system elements make it very difficult to isolate where a problem is occurring. This is further compounded by the fact that multiple standard interfaces may all need to be working properly to determine if the manufacturing systems do in fact interoperate. Testing methods for newer systems will need to be able to view the system behavior more abstractly and evaluate more complex responses.

In recognition of its neutral role, NIST has been asked to provide technical assistance to industry for development of methodologies and tools supporting the testing of these complex, information-driven manufacturing-system software components. The research being undertaken in this project is expected to not only improve the state-of-the-art with respect to testing but also lead to significant advancements in our understanding of metrology for information technology.

Technical Approach

The benefits and the limitations of conformance testing of implementations of data standards are fairly well understood. NIST has established expertise in conventional methods of conformance and interoperability testing. Testing controls must at a minimum: ensure that the results are repeatable, be well instrumented so that all system responses are measured, and support the tracking and storing of results for analysis. MEL has developed a flexible test environment that is potentially adaptable for supporting the testing methods described above.

Two emerging standards have been identified as having requirements suitable for this effort. These are the Standard Data Access Interface (SDAI) for the sharing of product data (ISO 10303-22) and the Process Specification Language (PSL) for process representation. Both of these specifications have dynamic characteristics that present the significant challenges of interest. SDAI has progressed sufficiently for prototype implementations to be available that could be used in the evaluation of any new testing methods.

The challenges posed by PSL and SDAI will be documented and used to assess alternative methods. Techniques for automating the test generation and techniques that appear appropriate for the evaluation of dynamic behaviors will be studied. Prototype modifications to an existing test environment will provide a platform for assessing the potential of the most promising techniques. Ultimately, a test system is needed that can provide the ability to modify the test specifications invoked so that they expose interesting system behavior and/or map closely to the applications being evaluated. Systemic planning techniques will be applied to look at end-to-end behavior that is expected to be present. Methods for automating the test generation, such as those under development in the Information Technology Laboratory will be explored. New techniques that allow for selective granularity of the testing will also be applied. The particular focus will be on the development of tests for dynamic or interactive systems that have a particular behavior specified in a data model or an interpretative component. This introduces events into a system that provides a stimulus that allows the system response to be measured.

Further study needs to include: appropriate test metrics for these systems, mathematical modeling techniques for testing, and the emergent behavior and agent approaches. Current tools and their potential use for testing of dynamic systems will be evaluated. We will analyze existing methods and tools for their potential for designing and building automated methods, tests and test suites for these event-driven systems. An architecture for developing a formal test environment (methods and tools) will be defined to enable invoking a test, identifying a model(s) to be evaluated, defining/selecting test assertions, and capturing/analyzing results. The architecture will emphasize the reuse of existing tools and methods where feasible. New test methods will be proposed to formalize and improve automation of test suites and control the interaction of systems under test. These methods will then be applied to the validation of PSL and SDAI implementations.

Related Developments

- The Standard for Exchange of Product model data (STEP) Conformance Testing & Interoperability (CT) project is working to develop methods and tools enabling conformance testing of STEP implementations. Current work in that project focuses on testing implementations of static information specifications. As more commercial implementations of dynamic specifications become available there will be a need for the CT project to deploy the results of this project.

FY 1998 Plans

- Document challenges (especially with respect to manufacturing systems needs), alternatives, and research needs
- Identify unique challenges to testing dynamic vs. static manufacturing software systems

Five Year Plan Goals vs. Fiscal Year

1998 Document Unique Challenges Posed by Dynamic Specifications

1999 Identify Methods/Metrics Applicable to Testing

2000 Develop/Adapt Testing System

2001 Pilot Test System for SDAI & PSL

2002 Formalize Testability Characteristics for Specification Development

2002 Deploy Testing Capabilities with Industry

XML for Workflow Management

Leader: Lubell, Joshua

Staff: New Hire - Student

Total FTE .45

1998 MEL Goals Supported

1. Laboratory research and development.
3. Information-based National and International Standards and Measurements

Project Objective

Explore the use of XML (eXtensible Markup Language), a standard for structured document interchange on the Web, for exchanging complex data objects between tasks in a distributed workflow application.

Needs Addressed

The increasing prevalence of virtual enterprises is driving a need to coordinate the efforts of individuals and teams using different computer platforms residing on different local area networks. Such coordination often requires the exchange of complex data objects among distributed applications. The Web has become a popular computing environment for virtual enterprises because it allows users on heterogeneous platforms to use the same applications and access the same data. The emerging XML standard provides a convenient and cost-effective way to define structured data objects to be shared among distributed tasks and applications on the Web. This project investigates the feasibility of XML as a means of reducing the cost to US industry of using distributed object technology for managing workflow.

Technical Approach

The WebWork workflow application development tool kit, created by the University of Georgia with funding from NIST's Advanced Technology Program, supports the building of distributed, web-based workflow applications. NIST has demonstrated the benefits of XML for representing highly structured documents such as product data standard specifications and has shown that WebWork can be integrated with an XML repository. Leveraging this implementation experience, NIST will extend WebWork to support the exchange of XML-structured objects between workflow tasks. NIST will demonstrate the efficacy of this approach by building a small application to manage a subset of the workflow in ISO TC184/SC4 (International Organization for Standardization Technical Committee 184, Subcommittee 4), an international standards body developing specifications for the representation and exchange of industrial data for which NIST serves as Secretariat.

FY 1998 Plans

- Obtain and install latest version of the WebWork software from the University of Georgia.
- Build application employing XML to manage subset of workflow for ISO TC184/SC4.
- Implement extension to WebWork allowing data objects to be passed between tasks using XML
- Choose an XML processor to be integrated with WebWork.
- Survey third party XML software development tools and existing XML applications.

Five Year Plan Goals vs. Fiscal Year

1998 Implement XML extension to WebWork [ATP Healthcare]

1999 Build workflow application for ISO TC184/SC4 [ATP Healthcare, APDE]

1999 Publish paper discussing XML/WebWork integration[ATP Electronic Commerce]

Standards & Measurement Services

Committees:

W3C Activity on SGML, XML, and Structured Document Interchange, ISO TC184/SC4.

Framework

Principle Investigator:
Neil Christopher
(301) 975-3888
neil.christopher@nist.gov

Project Objective

Accelerate the development and adoption of standards for distributed manufacturing systems through the implementation, testing, and analysis of emerging open industry specifications.

Needs Addressed

Manufacturers are attempting to gain the benefits that accrue when the meaningful information is transmitted rapidly to the appropriate systems in a usable form. However, these benefits or "economies of integration" are often offset by the high cost of systems integration. The cost of systems integration can be reduced by adopting 1) consensus models of information, 2) software component interface definitions, and 3) information exchange mechanisms. The rate of information technology change and large variety of available technology increases the risk that adoption of information technology will not result in competitive advantages for manufacturers. Information that results from the testing of emerging technologies is used to reduce the risks associated with technology adoption. New business models encourage manufacturing customers and suppliers to integrate information systems along supply chains. Analysis of the interrelationships between standards helps to uncover standards-based approaches to integration of enterprise systems.

National industrial consortia are working to develop standards and protocols that address parts of the overall open distributed systems problem facing the manufacturing industry. The Framework project has been asked by these consortia to contribute to this national effort by implementing, testing, and analyzing standards and protocols for manufacturing information systems. It is expected that the results of this project, when fed back to the consortia, will accelerate specification development and that the results, fed forward to the standards community, will accelerate industry consensus.

Technical Approach

The approach taken by the NAMT Framework project is to establish a process, system, and tools for testing emerging specifications that identify 1) consensus models of information, 2) software component interface definitions, and 3) information exchange mechanisms. The project team works with industry consortia and standards organizations to identify specifications that are open, that contain elements appropriate for standardization, and that are defined well enough to be the basis for prototype implementations. These specifications are implemented as prototypes in the NIST laboratory environment and tested with production test data against a manufacturing scenario to operate physical and simulated manufacturing equipment.

The Framework has begun its work on specifications emerging from SEMATECH, the RRM consortium, the TEAM initiative, the NIIIP program, the OMG, ISO 10303 Dimensional Inspection Data Exchange, and SDAI. The project also incorporates prior research performed at NIST including the Manufacturing Systems Integration project, the EMC project, the NGIS project, the Quality In Automation project, and the SIMA program.

The test system used to exercise these various specifications consists of manufacturing software applications ranging from electronic commerce (EC) applications, through enterprise requirements planning (ERP), manufacturing execution systems (MES), and machine control. The Framework test system also implements and examines underlying communication software (CORBA, JAVA, Active-X, DCOM and Shared Memory), heterogeneous computer platforms and operating systems, an ATM based network infrastructure, and physical manufacturing equipment.

Editor's Note: This is a NAMT project. A detailed description of all NAMT projects appears within the Office of Manufacturing Program's section. This project appears here because it directly ties into this division's core mission.

Commonly Used Acronyms

AE	Acoustic Emission
AAMACS	Advanced Automated Master Angle Calibration System
ACM	Association for Computing Machinery
ADACS	Advanced Deburring and Chamfering System
AE	Acoustical Emission
AFM	Atomic Force Microscope, Atomic Force Microscopy
AGMA	American Gear Manufacturers Association
AIAG	Automotive Industry Action Group
AMSANT	Advanced Manufacturing Systems Applications Networked Testbed
ANN	Artificial Neural Network
ANSI	American National Standards Institute
AP	Application Protocol
APDE	Application Protocol Development Environment
API	American Petroleum Institute
APTD	Automated Production Technology Division
ARM	Application Reference Model
ASA	Acoustical Society of America
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials (now called ASTM)
ASPE	American Society of Precision Engineers
ATEP	Algorithm Testing and Evaluation Program
ATP	Advanced Technology Program
ATS	Abstract Test Suite (related to STEP) or Algorithm Testing System
AWMS	Automated Welding Manufacturing System
BFRL	Building and Fire Research Laboratory
BIPM	Bureau International des Poids et Mesures (France)
C-AFM	Calibrated Atomic Force Microscope
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CALS	Continued Acquisition and Life Cycle Support
CAM	Computer Aided Manufacturing
CAME	Computer Aided Manufacturing Engineering
CASE	Computer-Aided Software Engineering

CBN	Cubic Boron Nitride
CENAM	Centro Nacional de Metrologia (Mexico)
CGPM	General Conference of Weights and Measures
CID	Charge Injection Device
CIFP	Capital Improvement of Facilities Project
CIM	Computer Integrated Manufacturing
CIMOSA	Computer Integrated Manufacturing Open Systems Architecture
CIRP	College International Pour l'Etude des Techniques de
	Production Mecanique
CMM	Coordinate Measuring Machine
CMS	Coordinate Measuring System
CNC	Computer Numerical Control
COGM	Committee on Gear Metrology (ASME)
CORBA	Common Object Request Broker Architecture
CRADA	Cooperative Research and Development Agreement
CSTL	Chemical Science and Technology Laboratory
DARPA	Defense Advanced Research Projects Agency
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DVM	Digital Voltmeter
ECSS	Expert Control System Shell
EEEL	Electronics and Electrical Engineering Laboratory
EIF	Enterprise Integration Framework
EMC	Enhanced Machine Controller
EMMA	Easily Manipulated Mechanical Armature
EU	European Union
FAMU	Florida Agriculatural and Mechanical University
FCIM	Flexible Computer Integrated Manufacturing
FEA	Finite Element Anaysis
FIPS	Federal Information Processing Standard
FSU	Florida State University
FTD	Fabrication Technology Division
FTP	File Transfer Protocol
GERAM	General Enterprise Reference Architecture Model
GMAW	Gass Metal Arc Welding

GOALI	Grant Opportunities for Academic Liaison with Industry (NSF program)
GPL	General Purpose Laboratory
GUI	Graphical User Interface
HMMWV	High Mobility Multipurpose Wheeled Vehicle
HPCC	High Performance Computing and Communications
HRC	Rockwell C Hardness
HTTP	HyperText Transfer Protocol
IAMS	Institute of Advanced Manufacturing Sciences
IDEF	Integrated Computer-Aided Manufacturing Definition
IDL	Interface Definition Language
IEC	International Electrotechnical Commission
IEEE	Institute of Electronica and Electrical Engineers
IGES	Initial Graphics Exchange Specification
IGRIP	Interactive Graphics Robot Instruction Program
IITA	Information Infrastructure Technology Applications (HPCC program)
IMGC	Instituto di Metrologia "G. Colonnetti" (Italy)
IPM	Intelligent Processing of Materials
IPO	IGES/PDES Organization
IR	Infrared (light)
ISATP	International Symposium on Assembly and Task Planning
ISD	Intelligent Machines Division
ISO	International Organization for Standardization – However, ISO
ITA	Interim Testing Artifact
ITL	Information Technology Laboratory
JAST	Joint Advance Strike Technology (a DOD program)
JEDMICS	Joint Engineering Data Management Information Computer Systems
JSW	Joint Standards Workshop
LFAD	Laser-Focused Atomically Deposited
LSI	Line Scale Interferometer
M3	Molecular Measuring Machine
MADE	Manufacturing Automation Design Engineering Project (a DARPA project)
MANTECH	Manufacturing Technology (a DOD program)
MBE	Molecular Beam Epitaxy
MEL	Manufacturing Engineering Laboratory

MES	Manufacturing Execution System
MfgTF	Manunfacturing Task Force (an OMG program)
MITT	Manufacturing Information Technology Transfer
MR	Manufacturing Resource
MRD	Materials Reliability Division (NIST Materials Science and Engineering Laboratory)
MSEL	Materials Science and Engineering Laboratory
MSI	Manufacturing Systems Integration
MSID	Manufacturing Systems Integration Division
NADC	Naval Air Development Center
NAMAS	National Measurement Accreditation Service (England)
NAMT	National Advanced Manufacturing Testbed
NC	Numerically controlled (machine tools and equipment)
NCS A&T	North Carolina State Agricultural and Technical University
NCMS	National Center for Manufacturing Sciences
NCSL	National Conference of Standards Laboratories
NGIS	Next Generation Inspection System
NII	National Information Infrastructure
NIIIP	National Industrial Information Infrastructure Protocols
NIM	National Institute of Metrology (China)
NIST	National Institute of Standards and Technology
NISTIR	National Institute of Standards and Technology Interagency/Internal Report
NORAMET	North American Metrology Cooperation (with NRC of Canada and CENAM of Mexico)
NPL	National Physical Laboratory (U.K. or India)
NRC	National Research Council (U.S. and Canada)
NRLM	National Research Laboratory of Metrology (Japan)
NSF	National Science Foundation
NVLAP	National Voluntary Laboratory Accreditation Program
OA	Other (government) Agency
OI	Operator Interface
OIML	Organization Internationale de Metrologie Legale
OMG	Object Management Group
OMP	Office of Microelectronics Programs

ORMC	Oak Ridge Metrology Center
OSRM	Office of Standard Reference Materials
PC	Printed Circuit or Personal Computer
PDES	Product Data Exchange Using STEP
PED	Precision Engineering Division
PMI	Phase Measuring Interferometer
PRT	Platinum Resistance Thermometer
PSD	Power Spectral Density
Pt-In	Platinum Iridium
PTB	Physikalisch-Technische Bundesanstalt (Germany)
PVDF	Polyvinylidenefluoride
PZT	Piezo-electric Transducer
Q&V	Qualification and Validation
QIA	Quality In Automation
RAMM	Rapid Agile Metrology for Manufacturing (an ATP sponsored program)
RAMP	Rapid Acquisition of Manufactured Parts (a DoD sponsored program)
RCS	Real-Time Control System
RRM	Rapid Response Manufacturing
SC	Subcommittee (under ISO)
SCLD	Scanning Capacitance Line Detector
SDAI	Standard Data Access Interface
SEMATECH	Semiconductor Industry Technology Consortium
SEM	Scanning Electron Microscope, Scanning Electron Microscopy
SET	Single Electron Tunneling
SGML	Standard Generalized Mark-up Language (an ISO standard)
SI	Systeme Internationale d'Unites (the modern metric system)
SIA	Semiconductor Industry Association
SIGMA	Supersonic Inert Gas-Metal Atomizer
SIMA	Systems Integration for Manufacturing Applications
SIMOX	Separation by Implantation of Oxygen
SIP	STEP Implementation Prototype
SOI	Silicon-On-Insulator
SOLIS	SC4 On-Line Information Services
SPM	Scanning Probe Microscopy, Scanning Probe Microscope
SQL	Standard Query Language

SRM	Standard Reference Material
STEP	Standard for the Exchange of Product Model Data
STM	Scanning Tunneling Microscope, Scanning Tunneling Microscopy
STRS	Scientific and Technical Research and Services (NIST appropriated budget)
STS	Scanning Tunneling Spectroscopy
SXPL	Soft X-ray Projection Lithography
TAG	Technical Advisory Group
TC	Technical Committee (under ISO)
TDP	Technical Development Plan, Technical Data Package
TEAM	Technologies Enabling Agile Manufacturing (DOE)
TEM	Transmission Electron Microscope, Transmission Electron Microscopy
TIMA	Technologies for the Integration of Manufacturing Applications (ATP program)
TIS	Tool Induced Shift
TLM	Technology Learning Modules
UTAP	Unified Telerobotic Architecture Project
UTRC	United Technologies Research Center
UHV	Ultrahigh Vacuum
US TAG	United States Technical Advisory Group
USPRO	United States Product Data Association
UV	Ultraviolet (light)
VA	Department of Veterans Affairs
W	Tunsten
WWW	World Wide Web
XCALIBIR	X-ray Optics Calibration Interferometer